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A PRELIMINARY HUMAN ENGINEERING EVALUATION OF HYPERBARIC CONTRO--ETC(U)

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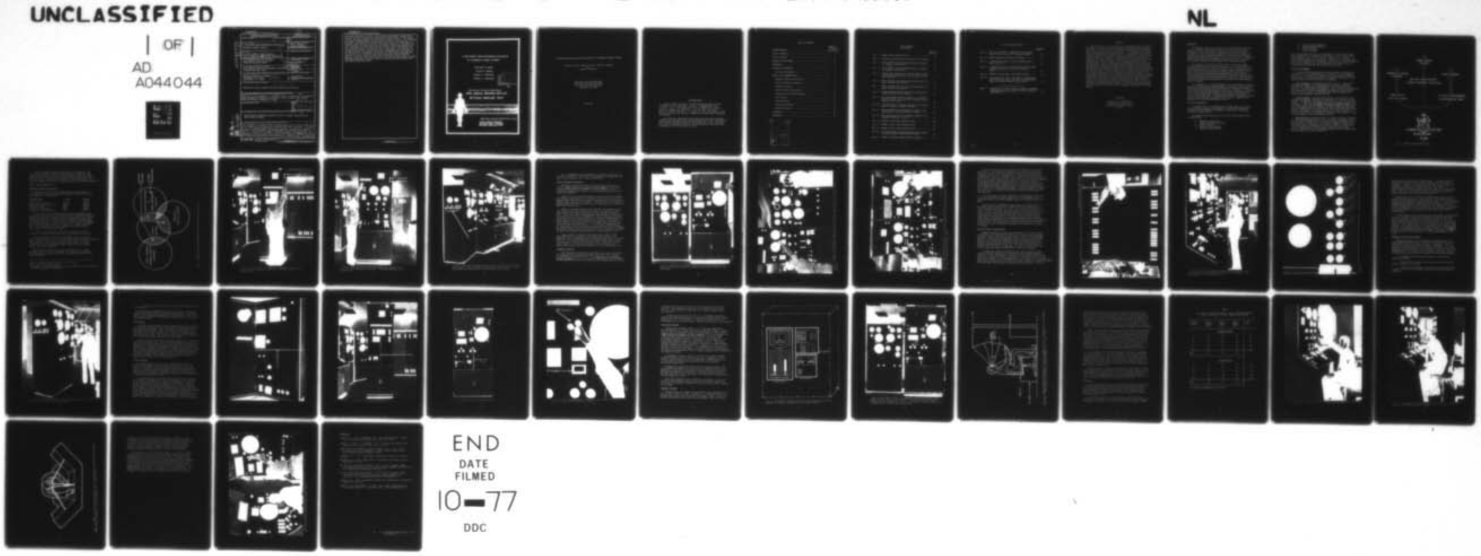

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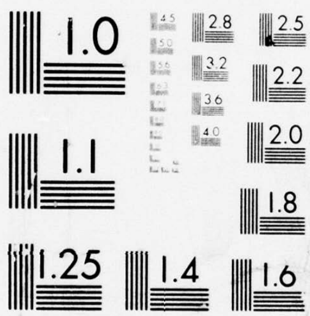
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Past experience in systems design has demonstrated that the use of human factors design criteria can maximize operator/system performance and safety. Yet there has not been adequate communication among operators, investigators, and design engineers. Poor functional interaction between man and machine has been the result. To minimize this problem in ~~our~~ a new hyperbaric research facility, ~~we conducted~~ an intensive human factors evaluation has been conducted. Hyperbaric engineering designs were utilized to construct full-scale mock-ups of control panels. The mock-ups

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evaluated using three criteria: (1) military human factors design specifications, (2) diver ratings and anthropometric measurements, and (3) empirically derived measurements from time-motion-reaction studies. The preliminary evaluation indicated several problem areas that need to be addressed: (1) frequently used controls and meters were often placed out of the operator's reach envelope; (2) some meters were positioned so that they preclude error-free interpretation of the information; (3) some control instruments were inconsistently placed in relation to their associated visual displays; (4) emergency controls were poorly positioned and designed which may increase the possibility of inadvertent activation; (5) some control instruments located on the side of control console were completely removed from the operator's field of view; and (6) other valve controls were spaced so closely that most experimental subjects could not activate one valve without unintentionally affecting others.

A PRELIMINARY HUMAN ENGINEERING EVALUATION OF HYPERBARIC CONTROL SYSTEMS

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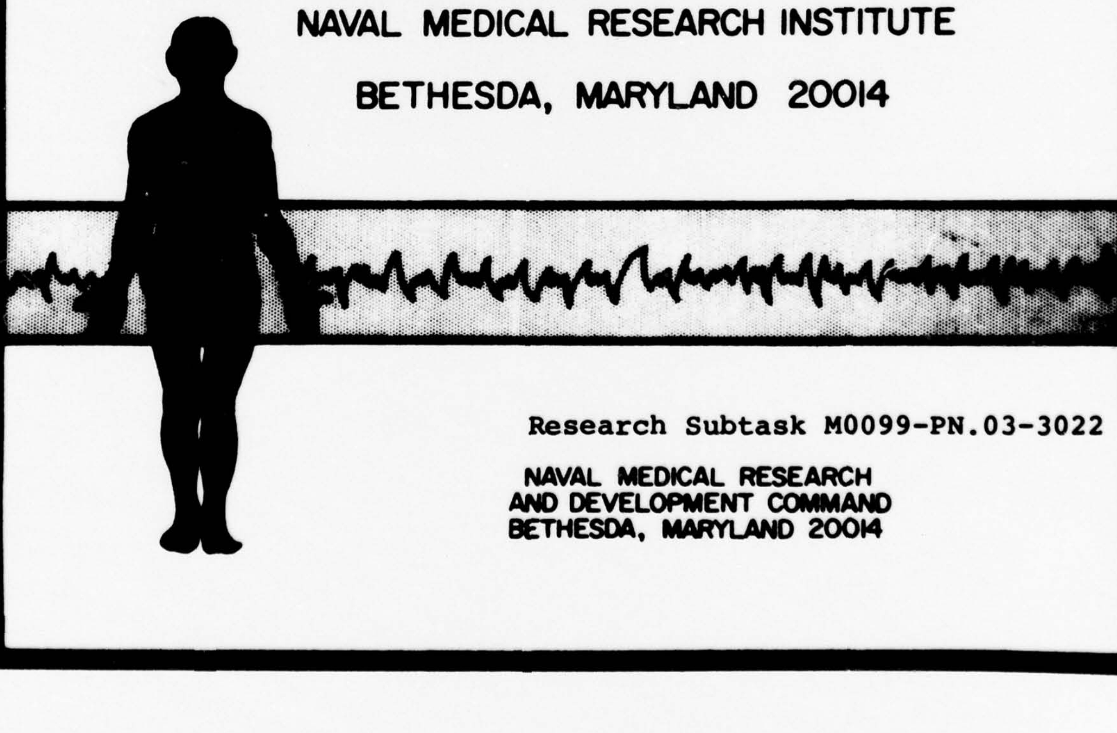

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ABSTRACT

Past experience in systems design has demonstrated that the use of human factors design criteria can maximize operator/system performance and safety. Yet there has not been adequate communication among operators, investigators, and design engineers. Poor functional interaction between man and machine has been the result. To minimize this problem in our new hyperbaric research facility, we conducted an intensive human factors evaluation. Hyperbaric engineering designs were utilized to construct full-scale mock-ups of control panels. The mock-ups were then evaluated using three criteria: (1) military human factors design specifications, (2) diver ratings and anthropometric measurements, and (3) empirically derived measurements from time-motion-reaction studies. The preliminary evaluation indicated several problem areas that need to be addressed: (1) frequently used controls and meters were often placed out of the operator's reach envelope; (2) some meters were positioned so that they preclude error-free interpretation of the information; (3) some control instruments were inconsistently placed in relation to their associated visual displays; (4) emergency controls were poorly positioned and designed, which may increase the possibility of inadvertent activation; (5) some control instruments located on the side of control console were completely removed from the operator's field of view; and (6) other valve controls were spaced so closely that most experimental subjects could not activate one valve without unintentionally affecting others.

KEY WORDS

human factors engineering
hyperbaric control systems
optimization of control design
safety

BACKGROUND

Past experience with new construction of hyperbaric facilities and diving systems has shown that in almost every case, costly and time-consuming retrofit activities were required to increase functional performance. Much time and money might have been saved if careful and thorough preconstruction human engineering reviews had been attempted before engineering drawings became "firm." We believe that if preliminary human factors analyses are adequately conducted, retrofit (along with its associated high cost) can be reduced to a significant degree.

This report is the first of a series that will focus on Human Factors Design Criteria and Systems Evaluation. It is hoped that the information presented will be used to identify possible deficiencies in future hyperbaric control systems, ~~to opti~~mize future hyperbaric control-panel designs, and to guide the anticipated retrofit construction/modification activities within the new hyperbaric research facility at the Naval Medical Research Institute (NMRI) in Bethesda, Maryland. The evaluation methods described are aimed at minimizing the cost of retrofit construction, reducing the probabilities for human error, and improving human performance.

The information to be reported emanates from a preliminary evaluation dealing with human factors design adequacy of hyperbaric control/displays developed for the hyperbaric research facility. Although the control-panel designs had been approved and fabrication was underway, a preliminary review of the engineering diagrams for the control panel revealed that the existing designs might contribute significantly to decrements in overall system performance: a thorough human factors engineering analysis appeared to be required. The scope of this report is limited to an analysis of the instrumentation/man interface.

MATERIALS AND METHODS

To conduct tests, we constructed control panel mock-ups to scale, using drawings[1] supplied by the designer. Control-panel components displayed on these drawings were fabricated from wood to the design engineers' specifications.

The Human Factors Evaluation of the control panels addressed the following areas:

1. Component accessibility
2. Control placement consistency
3. Control location
4. Control display adequacy
5. Emergency control design

6. Task-loading configuration
7. Optimal operator position
8. Control spacing
9. Control grouping

From the preliminary analysis it was apparent that many other systems aspects would have to be evaluated, for example: visual coding, information feedback, angle of view, scaling, illumination, dial markers, manning configuration, space limitations, and training. These and other areas will be addressed as the contractor provides more detailed information to include in our mock-ups. The results of such evaluations will be reported after the data have been collected and analyzed.

Criterion Development

To provide the optimum vehicle for our preliminary evaluation, we decided to use a three-pronged attack, the multiple-criterion approach (see Fig. 1). We believe that a multiple-criterion approach provides a greater degree of criterion relevance, increases the reliability of our appraisal and the generalizability of our findings.

First criterion. From personal interviews with U.S. Navy divers/ operators, we learned that design suggestions regarding hyperbaric panels had not significantly influenced the initial design of these displays. To add this kind of information, and to provide both quantitative and qualitative information regarding design adequacy from the diver/ operator's point of view, we developed check lists and Likert-type rating scales (Sidowski, 1966, pp. 613-615).

Second criterion. Military specifications (MIL-STD-1472B, 1974), although very general, frequently are employed as a criterion for design adequacy. We therefore used many of these specifications as evaluative criteria. In addition, The Engineering Guide to Equipment Design (VanCott and Kinkade, 1972) offers a wealth of information regarding empirically derived recommendations and standards for human engineering evaluations. Since we assumed that the design engineers had incorporated these Military Standards and Human Factors Design criteria into their equipment, we were most interested in evaluating the hyperbaric control panel in terms of how adequately these specifications were met.

Third criterion. Other Navy facilities operate hyperbaric equipment, yet often these systems differ not only in hardware configuration but in the operating environment and in the required operating manning levels. Because of this variability, it was decided to conduct in-house studies when human factors information was either too general or inapplicable. It was intended that our studies would account for unique system-specific characteristics and maintenance procedures that otherwise might be overlooked in the overall evaluation.

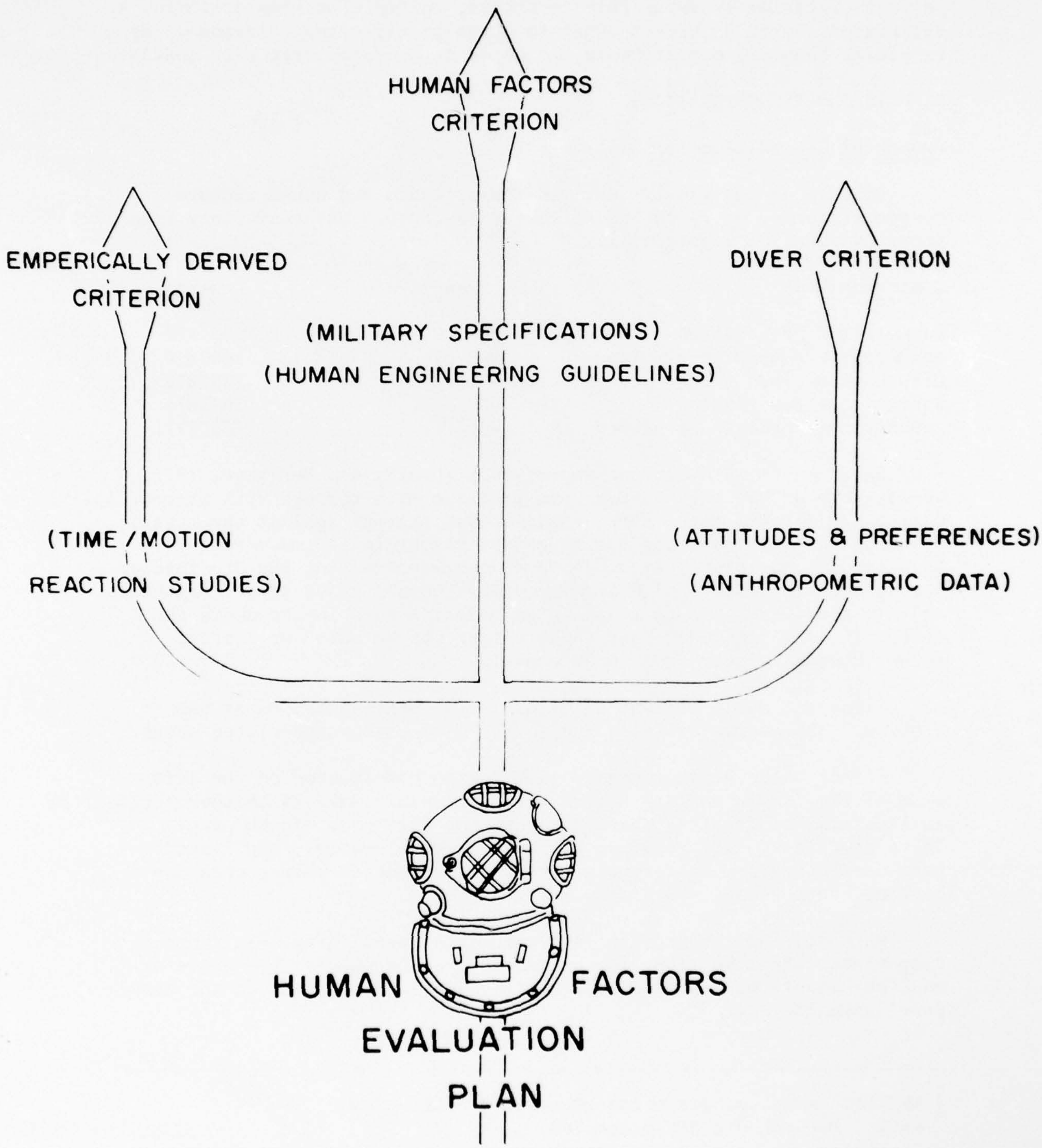

Fig. 1. Human Factors Evaluation Plan.

Figure 2 provides a graphic illustration of our rationale. The circle labeled "perfect criterion" theoretically represents the ideal criterion for evaluating overall system performance. Because a single perfect criterion is impossible to obtain, multiple working criteria, as delineated above, provide a means to optimize criterion relevance. By carefully choosing our criteria, we hoped to minimize criterion contamination.

RESULTS AND RECOMMENDATIONS

Component Control Accessibility

Based upon empirically derived measurements and human factors design criteria, we rated the following components unsatisfactory from the standpoint of accessibility.

Component Name	Panel	Drawing
Annunciator test button	MRC OP[1]	3007870
Annunciator acknowledge button	MRC OP	3007870
Elapse-time clock	MRCC[2]	3007872
Annunciator test button	MRCC	3007871
Annunciator acknowledge button	MRCC	3007871

Based on known diver anthropometrics (Beatty and Berghage, 1972), we determined that only Navy divers from the 85th through 99th percentile-height could reach these components without leaning against the console, standing on their toes, or making gross, uncoordinated movements from the standing position. A sample of divers representing the 5th through 35% percentile-heights of U.S. Navy divers[3] could reach these components only if they were able to stand on an object 3 to 5 inches above the deck. It is recommended that these components be moved at least 6 inches downward toward the lower console.

Figures 3 and 4 present an illustrative representation of the problem. The arrows are pointing to the five components listed above.

Direct observation revealed that components located on the left side of the local panel in Fig. 5 were accessible only if an operator/monitor walked from the front of the console to the left side of the panel. These components, all relating to sanitary-tank control, are listed: pressure indicator, differential pressure, isolation valve, pressure button, vent, flush, and drain.

When viewing the front of the same local panel (Fig. 5), these components cannot be seen. To manipulate the components, the operator must physically move around to the side, leaving the front of the local panel unmonitored.

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[1] MRC OP: Monitoring control console, operating panel.
[2] MRCC: Man-rated chamber complex.
[3] Percentage is based upon laboratory study of samples that are representative of Navy anthropometric distribution.

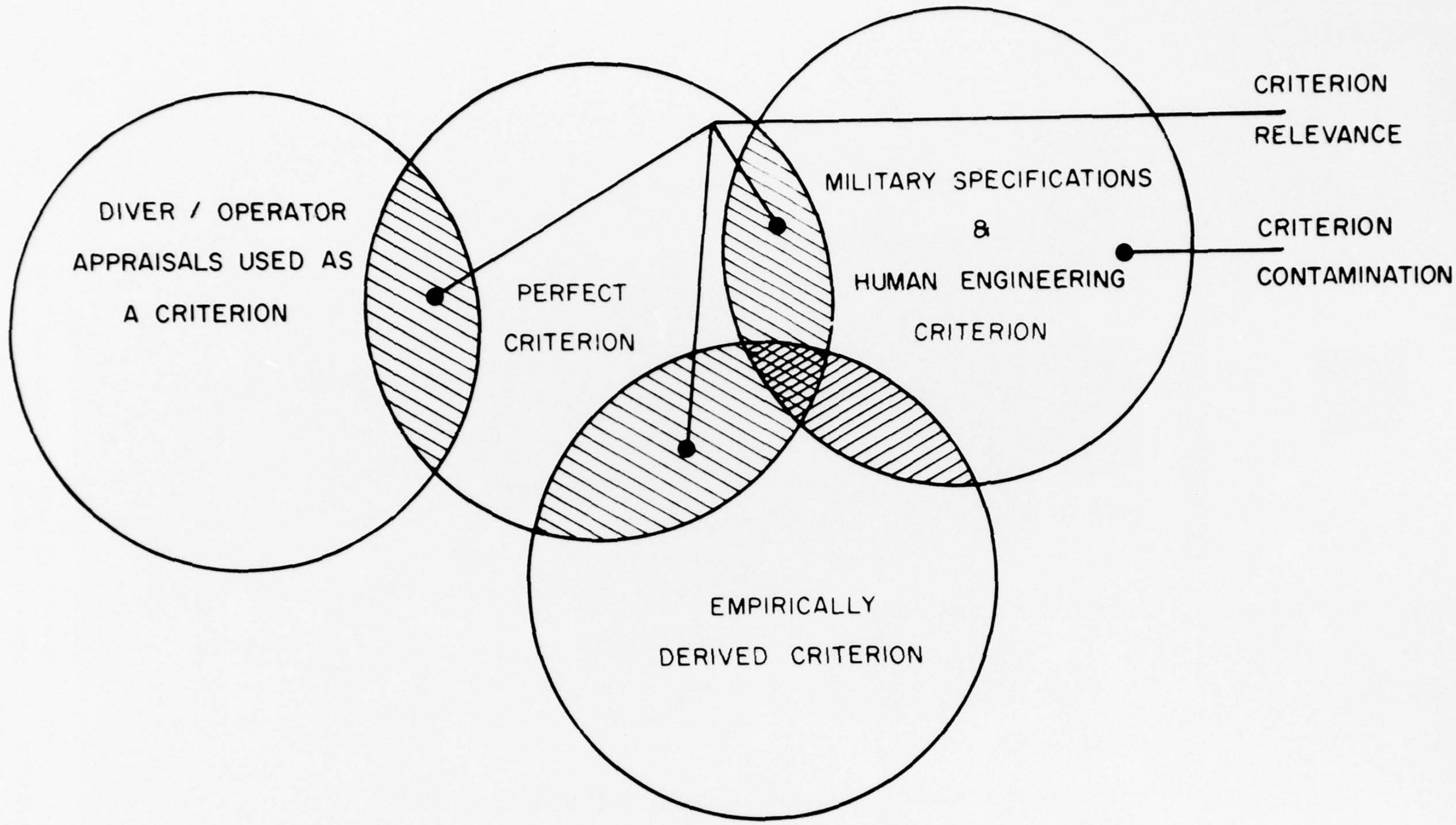

Fig. 2. Theoretically based rationale for the evaluation of the system.

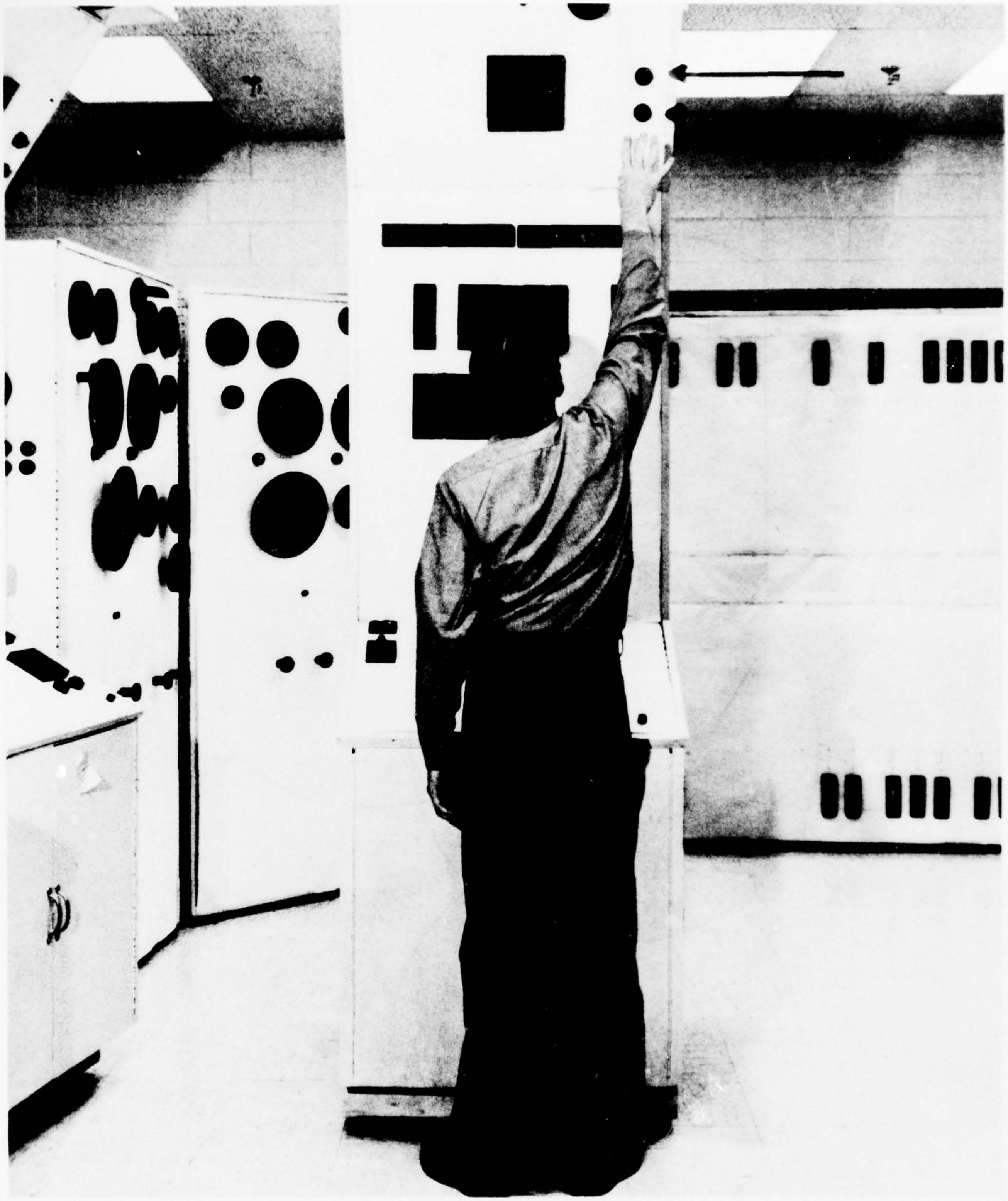

Fig. 3. Panel #3007872 was rated unsatisfactory in regard to the specification of component accessibility. (The human operator is 5 ft 10 inches tall.)

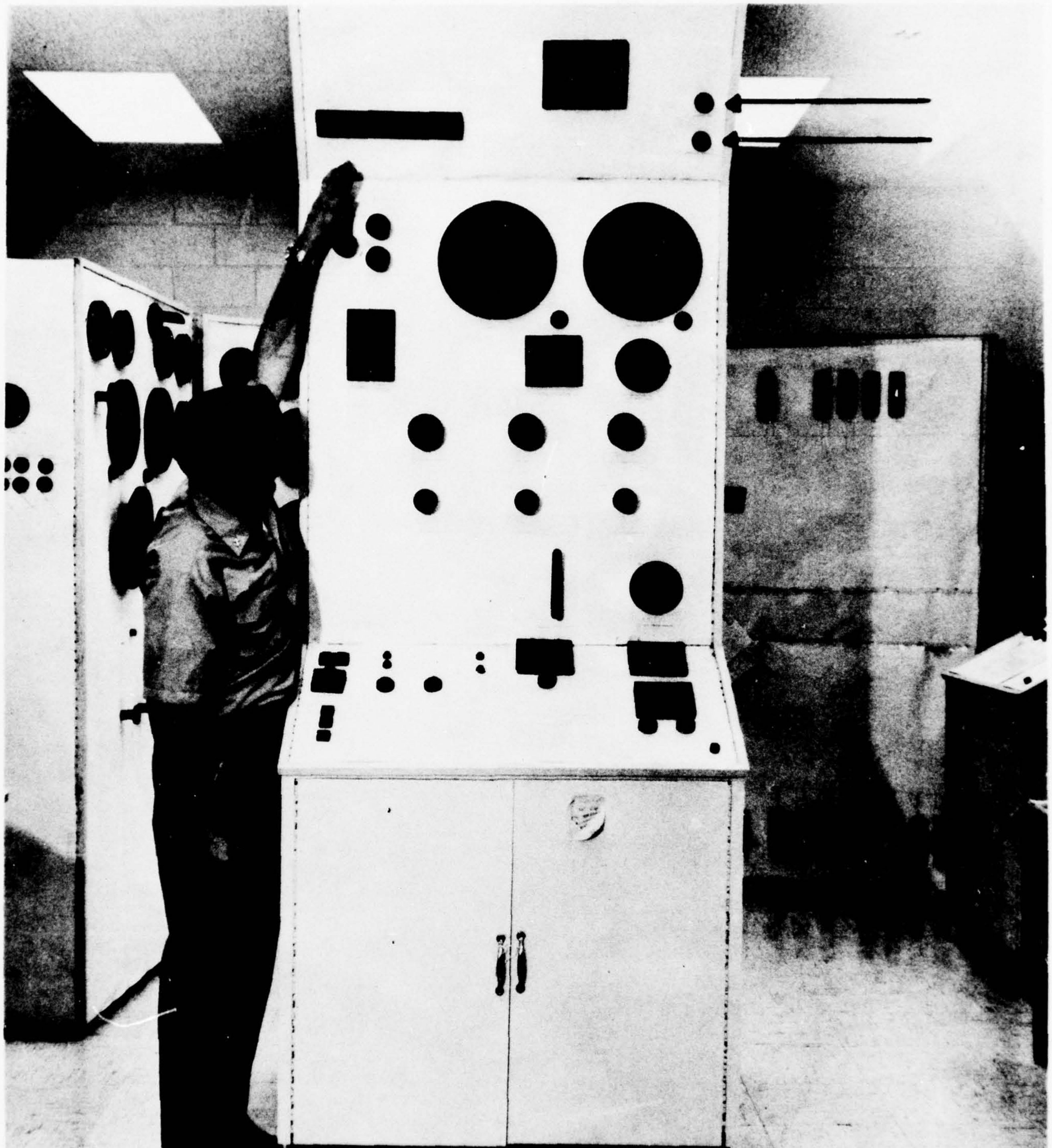

Fig. 4. Panel #3007870 was rated unsatisfactory in regard to the specification of component accessibility. (The human operator is 5 ft 6 inches tall.)

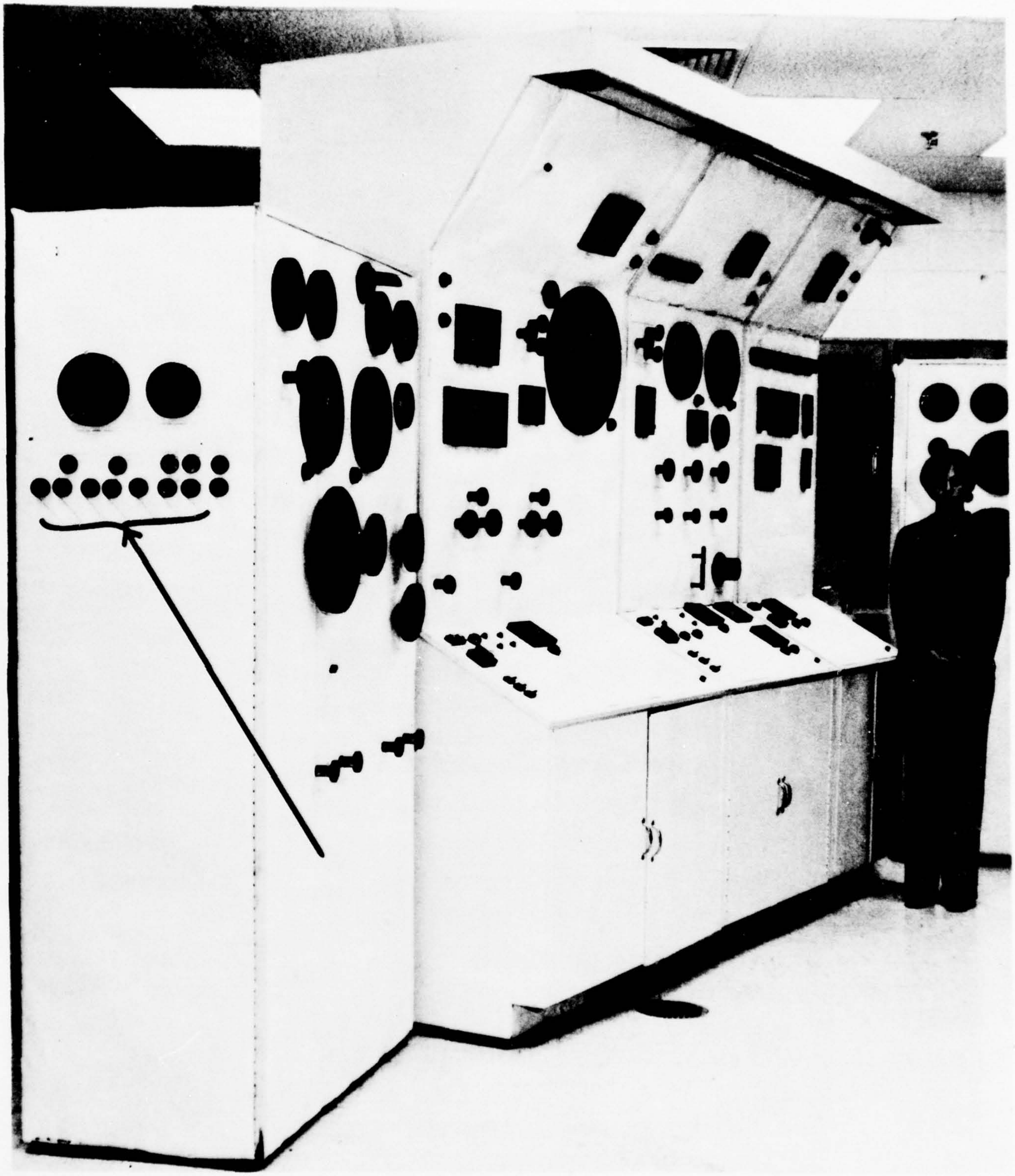

Fig. 5. Local panel #3007874 shows the relative position of the sanitary drain controls. This side panel should be swung toward the front so that all controls and indicators are in the monitor's line of sight.

It is recommended that the components listed above be displayed on the front of the panel. This could be accomplished by swinging the side panel out and around so that it faces the operator.

Control Placement Consistency

Based upon information obtained from known human factors design criteria (Human Factors for Designers of Naval Equipment, 1971) it was believed that the physical placement of similar controls should be consistent throughout the system so as to decrease operator search-time, errors, and confusion.

Figure 6 is an illustrative example of a violation of this standard. Note that the display panel of the control console on the left has two pressure meter shut-off valves placed to the lower left of their respective meters on this local panel (see arrows). The console on the right has a pressure meter shut-off valve located to the lower right of its respective meter (see vertical arrow).

Figure 7 is another example of this problem. The operator on the left is pointing to the meter-shut off valve on one local panel, while the operator on the right is touching the same component on another panel. Notice the reversed positioning of these controls (inconsistency). It is believed that such an arrangement may lead to operator confusion. Interviews with divers indicated that this situation is undesirable from their point of view. Their unanimous opinion was that the shut-off valves should be consistently placed to the lower right or bottom center of the associated pressure meters. It is therefore recommended that the lower-right or lower-center area of an associated circular indicator be consistently used as the location for meter shut-off controls throughout the system. Another example of inconsistency in the placement of specific controls can be found by contrasting the two control panels in Fig. 7.

Figure 8 shows two operators pointing out the position of the oxygen manifold in relationship to the oxygen meter display. These panels show that the oxygen manifold controls have been placed in different locations. In a similar manner, the associated display meters (oxygen-level controller) are also inconsistently placed relative to these two control panels. The functional grouping of these instruments in a logical association is not at all obvious. This will be discussed later.

Component Location

From information obtained from experienced Navy divers and from the literature dealing with component location (McCormick, 1975; Chapanis and Lindenbaum, 1959; MIL-STD-1472A, 1970; Human Factors for Designers of Naval Equipment, 1971,) it is clear that components are better located at positions which are most easily observed with minimal operator movement.

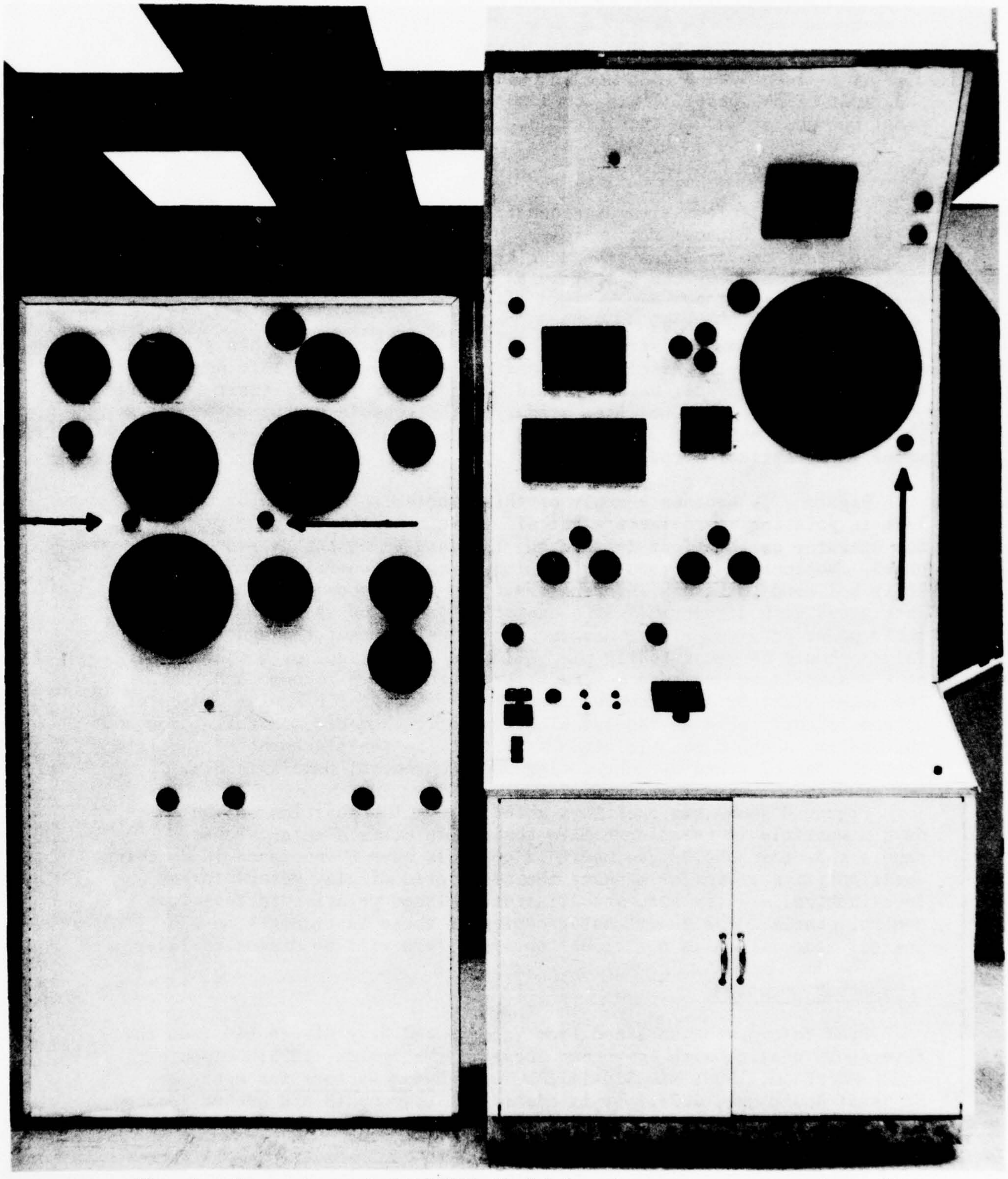

Fig. 6. Control panel #3007874 (left) has its control meter shut-off valves inconsistently placed in relation to control panel #3007871 (right). Note arrows.

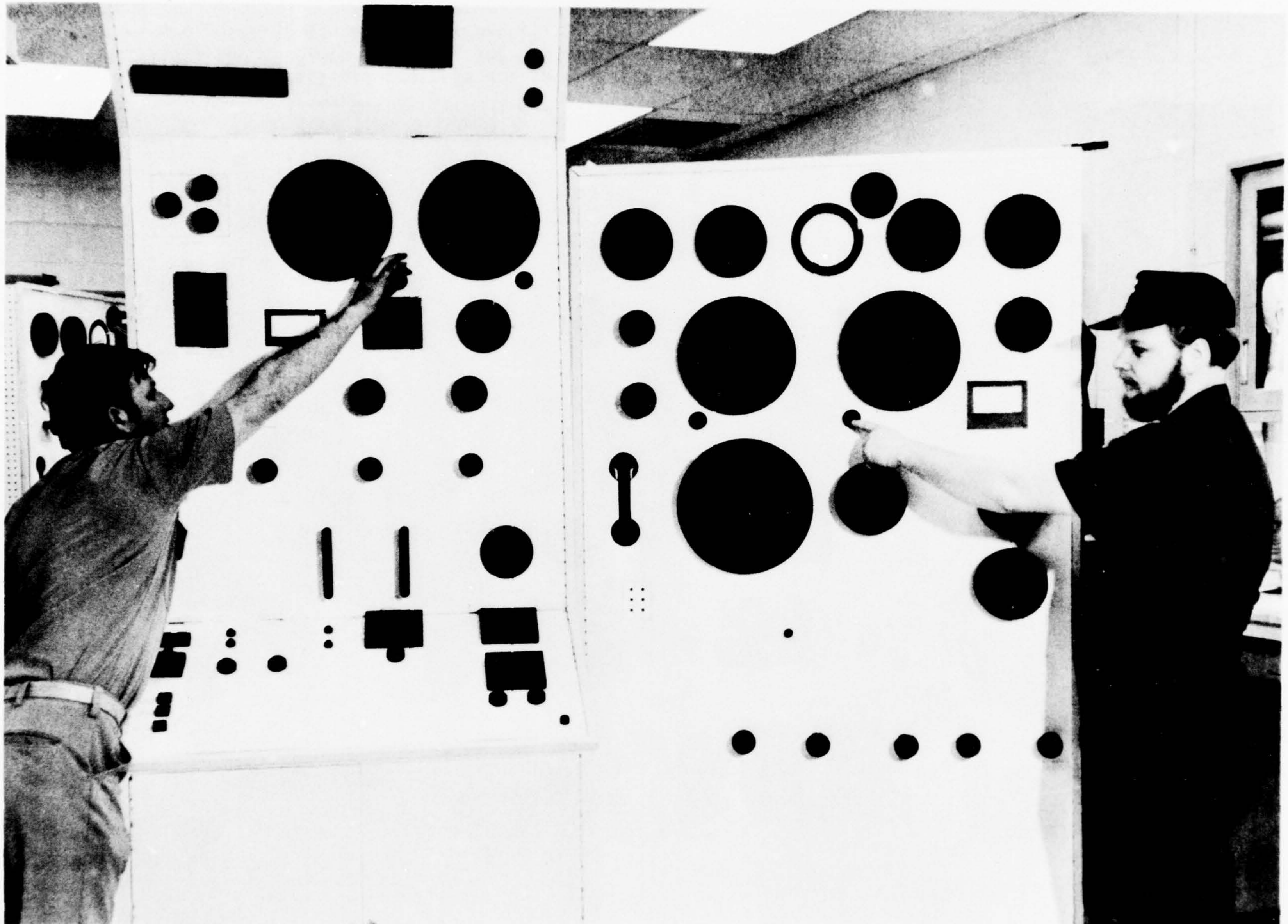

Fig. 7. Control panel #3007874 (right) has its control meter shut-off valves inconsistently placed in relation to control panel #3007872 (left). The men in the picture are pointing to these controls.

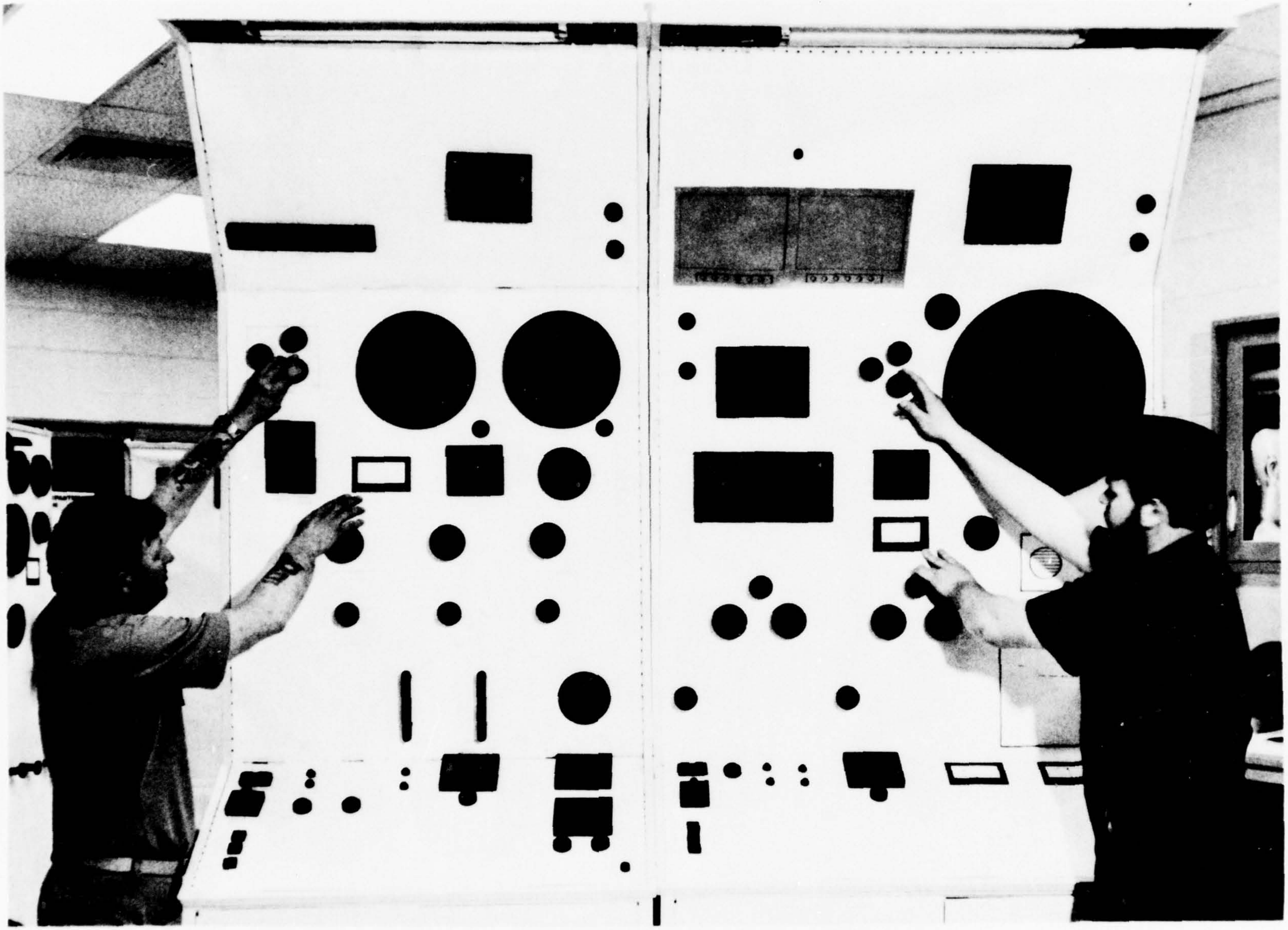

Fig. 8. The oxygen manifold controls are inconsistently placed with respect to control panels #3007872 (left) and #3007870 (right). The men are pointing to these controls (upper arms). Their lower arms are pointing to the display meters.

Tests were conducted to learn whether the hyperbaric gas-storage panel (Fig. 9) could meet this requirement and whether it would allow operators to locate information quickly without excess bodily motion (bending, turning, etc.). Figure 9 offers a photographic frontal view of this panel. Note that the indicator components at the bottom of the panel are 12 inches from the deck. The results of our tests are inadequate at the present time, because we did not have information needed to construct the dial faces, numbers, and scales. We were, however, able to determine that direct visual access to the information presented via these components required operators either to back away from the panel by at least 2 feet (assuming the operator is normally standing 12 inches from the panel) or to bend over to a point where the viewing angle is less than 125°.

It is suggested that these components be moved upward on the panel by at least 21 inches to decrease the present viewing angle and to reduce the amount of operator movement required to examine these instruments.

Another example of suboptimal positioning can be seen in Fig. 10. The large, round, circular disk in front of the diver represents a pressure/depth gauge meter. The diver in the picture is slightly over 5 feet 10 inches tall (65th percentile-height, Beatty and Berghage, 1972). As can be seen, the diver has good direct visual access to the lower portions of the meter, however, the greater part of the meter, representing mid-range depths, is clearly placed out of the optimal visual angle. Virtually all of the experienced divers who were given check lists indicated that the meter should be placed in a lower position on the console. The seated diver, and those that fall below the 50th percentile in height, would have an especially difficult time reading this gauge.

<u>Control Display Relationships</u>

Numerous human factors guidelines (McCormick, 1970, 1975; VanCott and Kinkade, 1972; MIL-STD-1472A, 1970) have stressed the importance of creating a logical connection between displays and their associated controls. In our study of hyperbaric control systems, we tested divers (<u>n</u>=4) to see if they could determine a clear functional relationship between controls and their associated indicators without labels on the controls and indicators (see Fig. 11). The results confirmed our hypothesis that the current configuration is lacking in this regard; all divers tested were unable to identify the correct relationship.

An additional finding indicated that the control sequence of the sanitary draining components was inconsistent with defined procedural operation. Since the procedures instituted during sanitary draining are known to be extremely critical to the safety of the diver enclosed in the pressurized chamber, it is recommended that a greater degree of sequential compatibility be incorporated into the panel design. Figure 11 displays the side of the local panel that contains the sanitary draining controls. Note the

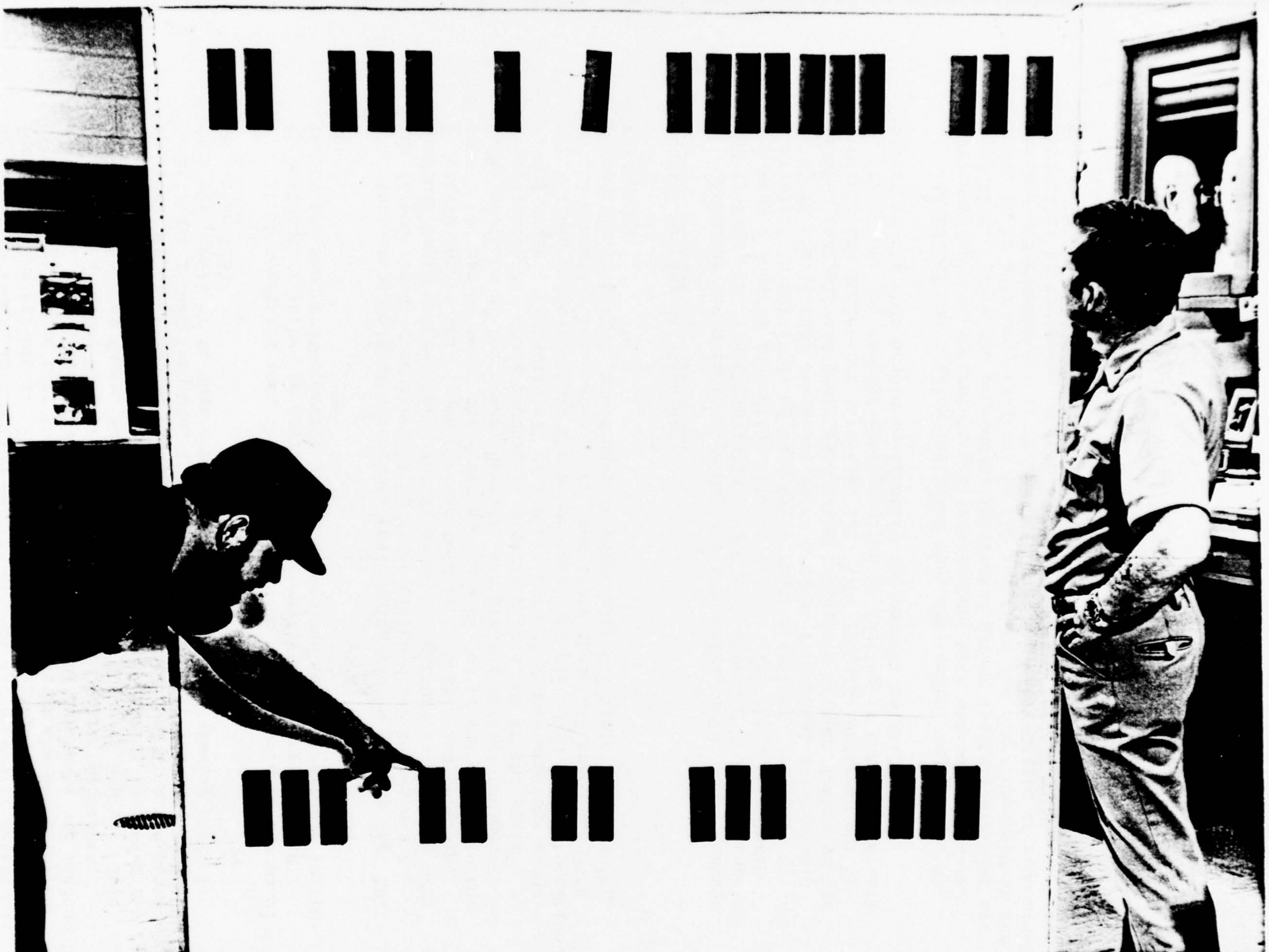

Fig. 9. Gas control farm #3007875 exemplifies a situation where components are susceptible to operator impact and poor visual access.

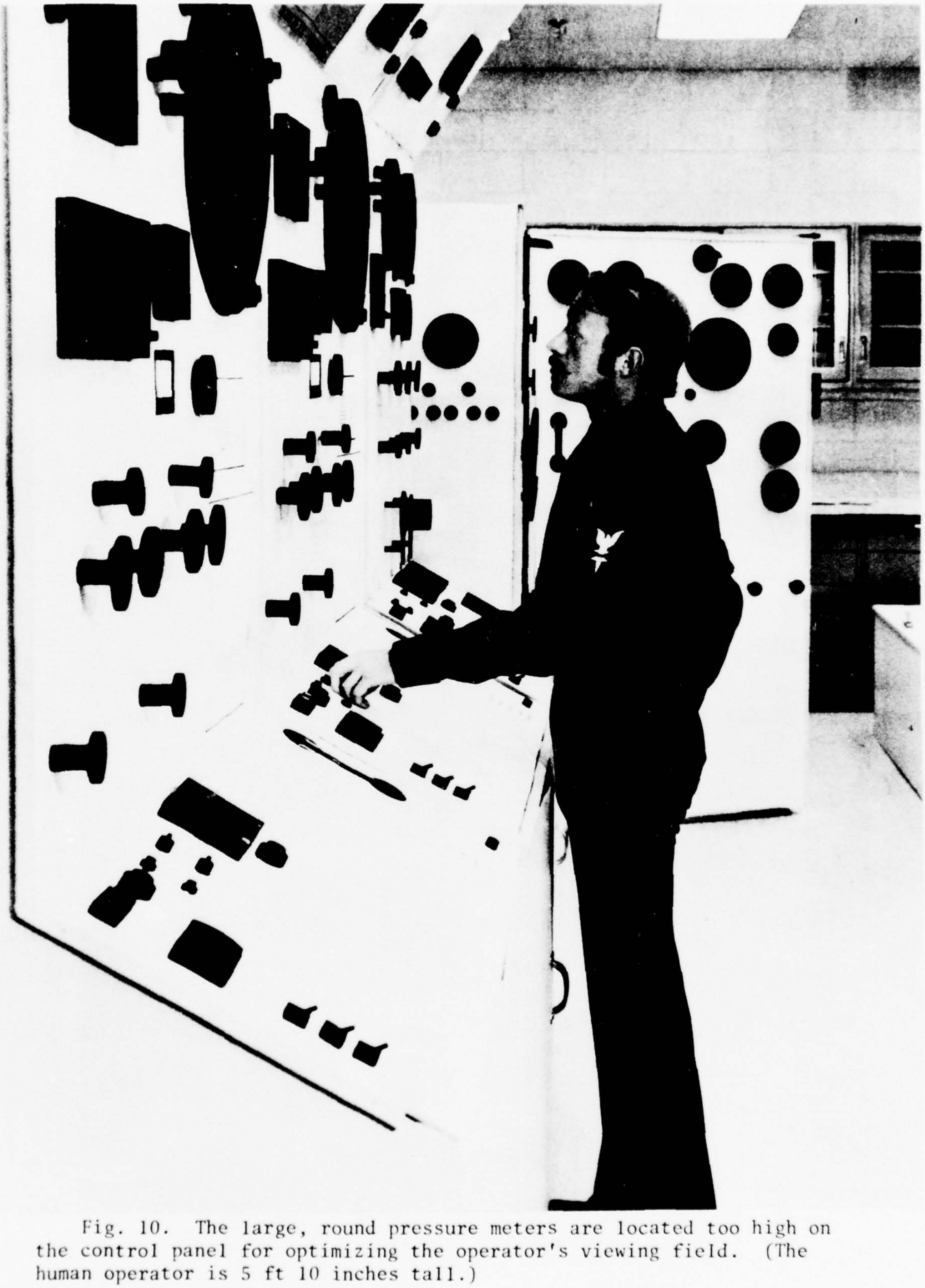

Fig. 10. The large, round pressure meters are located too high on the control panel for optimizing the operator's viewing field. (The human operator is 5 ft 10 inches tall.)

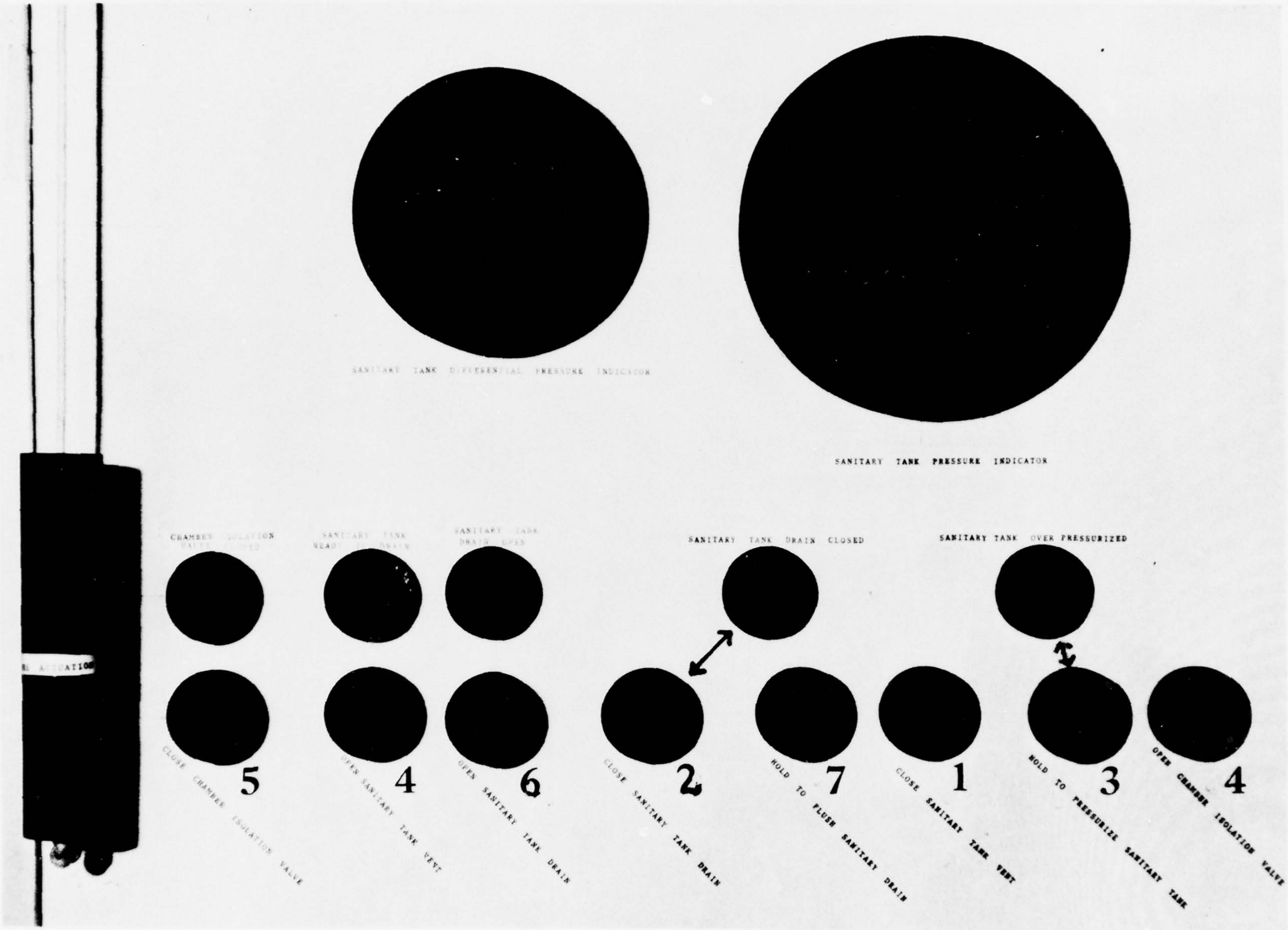

Fig. 11. Side panel local #3007874 is used for sanitary draining. Control/indicator relationships are vague.

numbers located just below each control button. The numbers represent the sequence of control actions employed during a sanitary draining procedure. It would be far better for an operator to move through this sequence in a smooth left-to-right direction. This could be accomplished by placing the sanitary-tank vent close control on the far left, followed by the sanitary-tank drain close control, pressurization control, and so on, until finally control #7 would placed on the far right of the panel, at the position now labeled #4.

The arrows in Fig. 11 are pointing toward control lights and their associated activation buttons. Notice that two of the lights are not aligned with the appropriate activation button. These existing relationships between control and display should be made more explicit. It is further recommended that controls associated with valve-closing procedures be clearly distinguished from those controlling valve openings. The reasoning for this recommendation is obvious when one considers the consequence of inadvertently opening a low-pressure line when the sanitary tank is under pressure.

Another example of poor control-display relationships is demonstrated in Fig. 8. Without telling divers the names of blocked-in controls on the panel mock-ups, we asked them to point out the display that they felt to be most likely related to the oxygen manifold. In each instance they picked the FES differential pressure indicator, which of course was incorrect. This demonstration led us to conclude that the oxygen control indicator was not placed properly in relationship to the oxygen manifold controls. We recommend that this situation be changed. To increase the perceived relationship between these instruments, we suggest that they be moved physically closer together in a tight group bounded by strip-lines.

Emergency Control Design Adequacy

Figure 12 displays the fire-extinguish activation lanyard. The fire-extinguishing system (FES) is activated by pulling this lanyard in a downward motion after grasping the handle. The handle is free to swing and is situated well within the working environment. It is thus exposed to a higher probability of accidental activation because of the swinging motion of the cord to which the handle is attached. It will be important for us in the future to have knowledge of the force required to activate this system in order to address this system more adequately.

It is suggested that the following changes be incorporated to remedy these problems.

1. Place the FES activation handle further up and away from the working environment of the panel.

2. Substitute a fixed-handle, single-motion lever instead of the lanyard so as to allow easy emergency operation and prevent accidental activation.

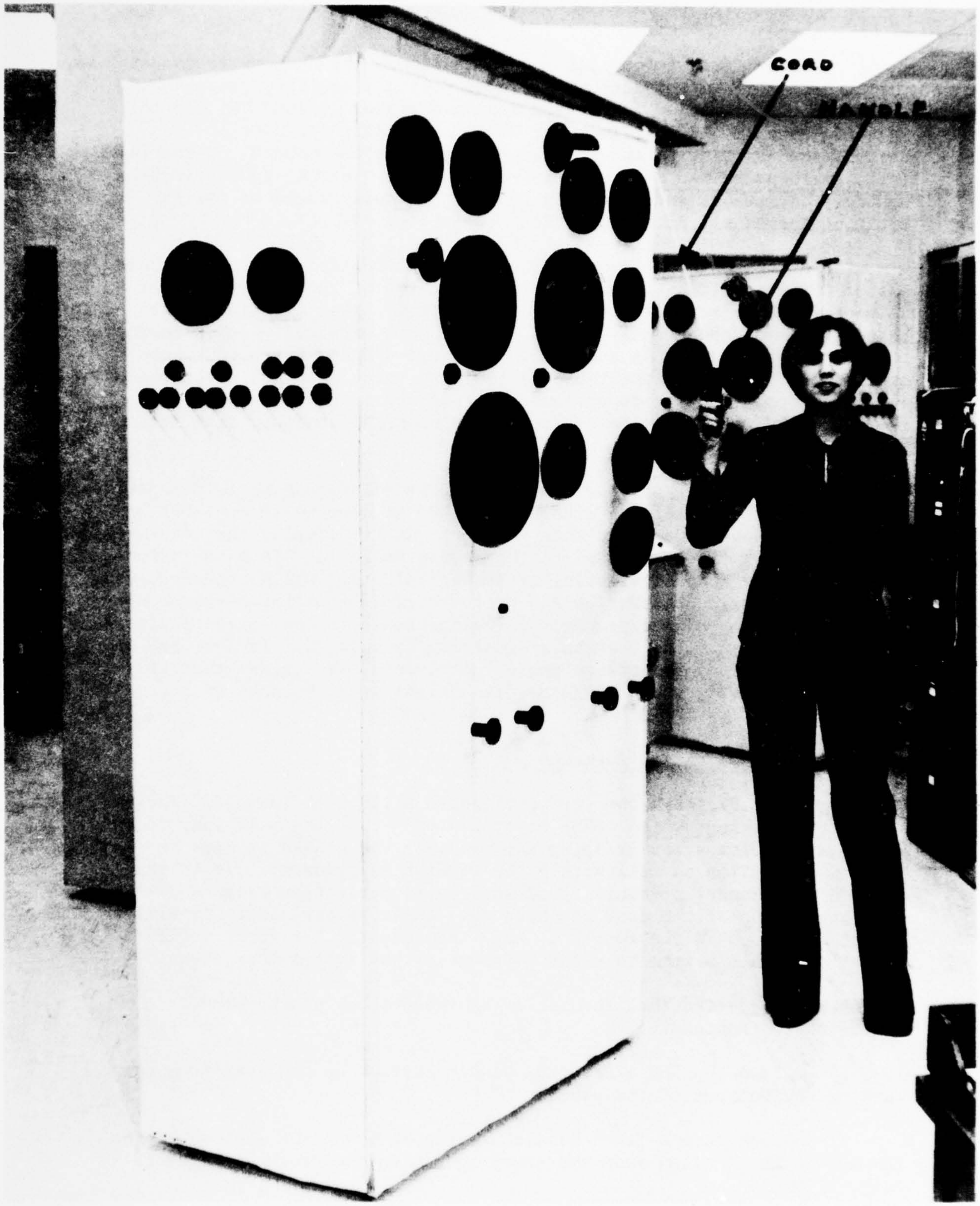

Fig. 12. The relative position of the fire emergency lanyard is shown. Note its proximity to the working environment.

3. Locate the FES actuation arm at the front-top of the panel and clearly mark it.

We make these recommendations because seven of the eight divers tested considered the current configuration undesirable. Furthermore, human factors engineering guidelines (VanCott and Kinkade, 1972) stress that accidental activation of emergency equipment should be reduced to an absolute minimum.

Task Loading

Military specifications for human engineering designs specify that console designs should allocate a larger portion of the control task to the operator's right hand. Figure 13 displays a control panel with three functional controls located to the right of the midline mark on the panel. To the left of midline are 11 functional controls, most of which are power-related. This configuration would only be acceptable if all or most of the control operators were left-handed.

Figures 14 and 15 show a similar situation where all five functional controls are situated to the left of the panel midline mark. These panels present more of the work task to the left hand of a control-panel operator. It is therefore recommended that controls be convenient to the operator's right hand, which shares the larger portion of the control task. Control placement should also be dictated by the priority of task function, where high priority and frequently used components would be located in the upper-right quadrant or the most easily accessible area of a panel. Frequency-of-use studies will be conducted in the near future and the results will be published for use.

Control Spacing

The oxygen manifold is part of the oxygen make-up system. It consists of one bypass and two isolation valves; it is used to add oxygen to the chamber in a predetermined concentration. This system (Fig. 16) is manually operated and provides visual information to the operator via the oxygen-level controller, which is a display meter. This meter gives the operator time-delayed feedback as to the percentage of oxygen in the hyperbaric chamber.

Six experienced Navy divers were asked to turn the valves of the oxygen manifold and report on the ease or difficulty of this operation as it relates to the clearance of their fingers/knuckles. Figure 16 provides an illustration of this operation. Five of these six diver subjects reported that the spacing between these valves (1) retarded their efforts, (2) caused unwanted contact with one or more other valves, and (3) required that they orient their wrist/arm in an unnatural position. In addition, two of these six divers (5 feet 6 inches and 5 feet 7 inches in height) reported that the oxygen manifold was placed too high on the panel relative to its associated importance. Although these reports were subjective, virtually all of these six divers were observed

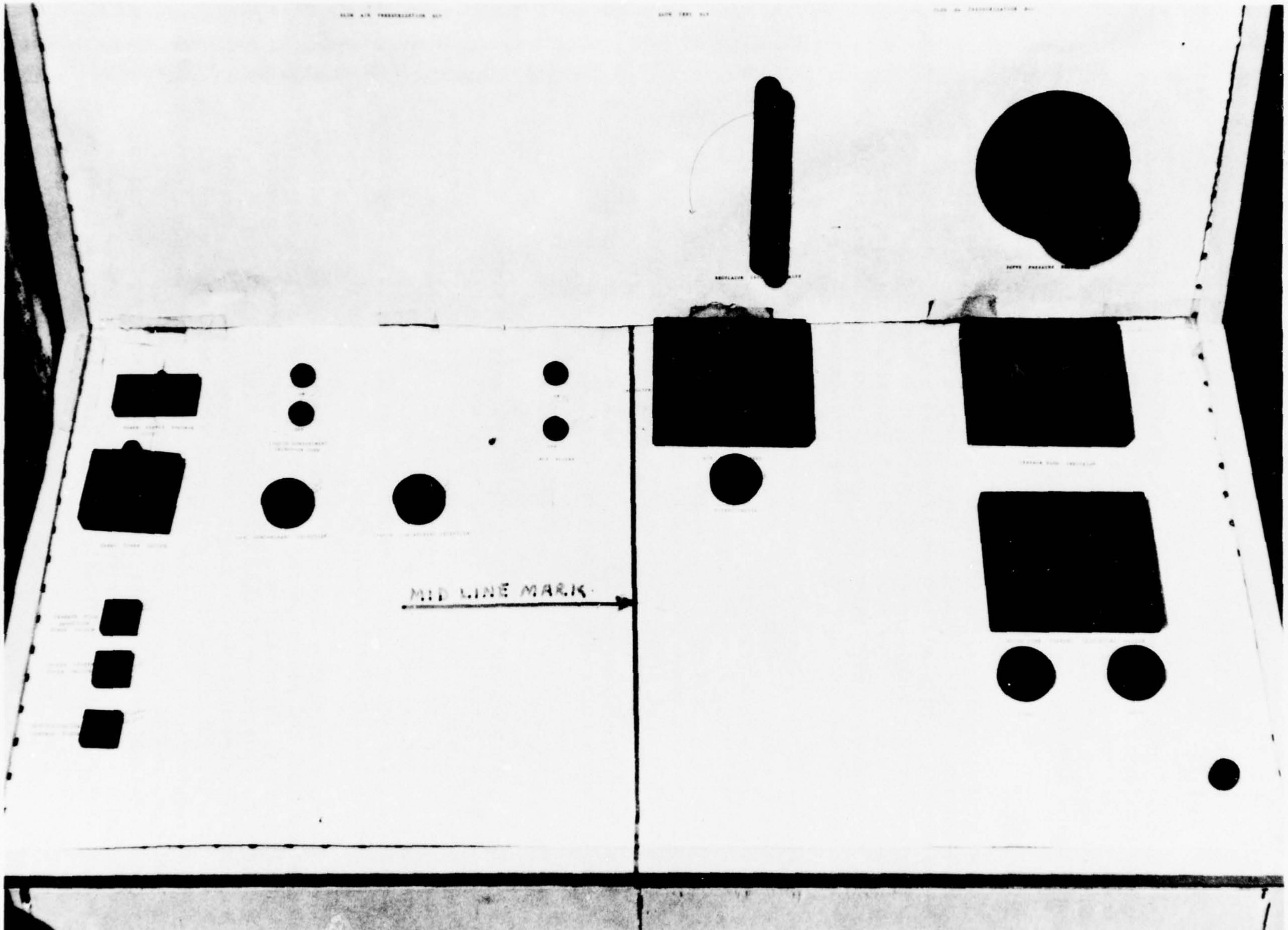

Fig. 13. Example of poor task-loading decision.

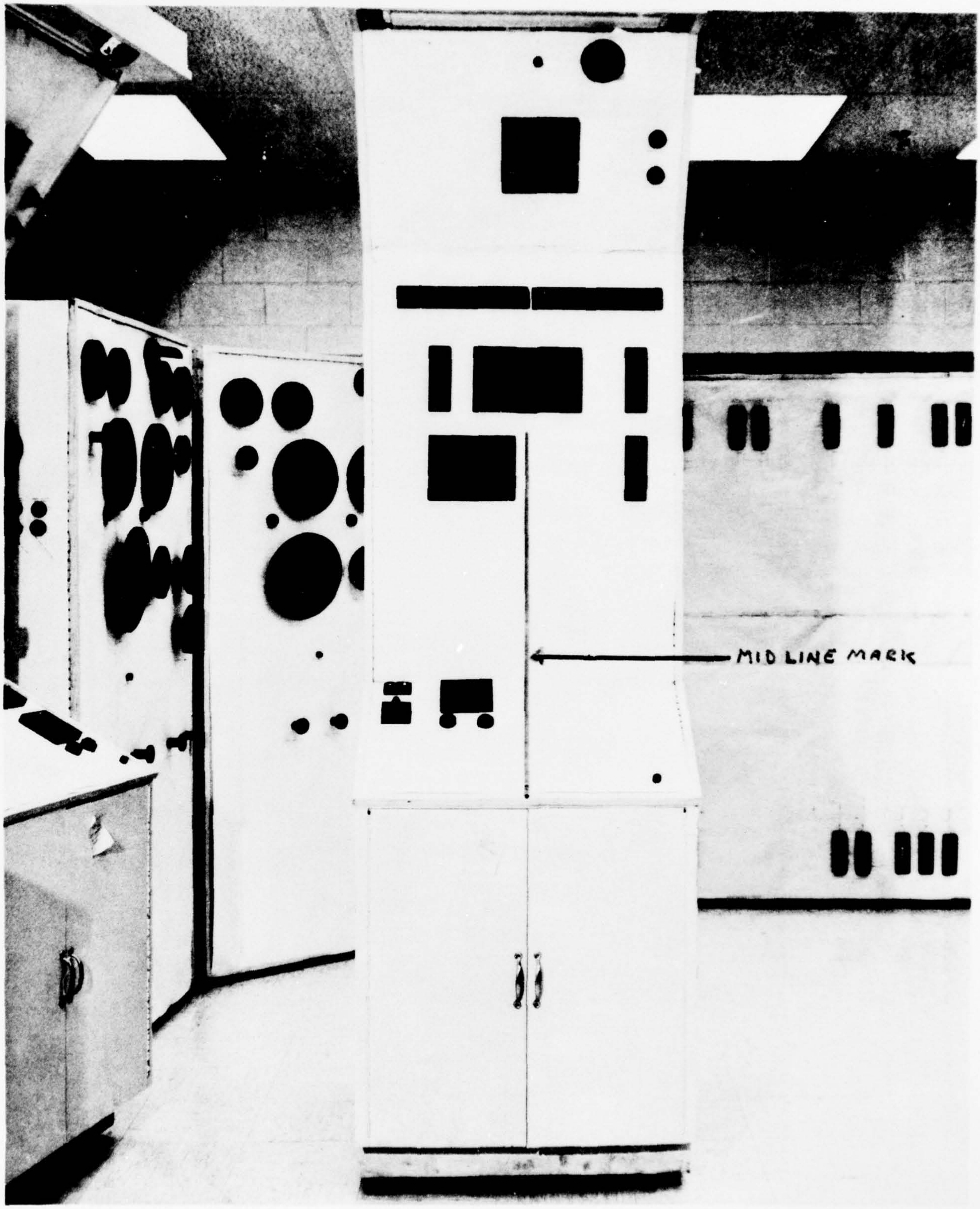

Fig. 14. Example of poor task-loading decision.

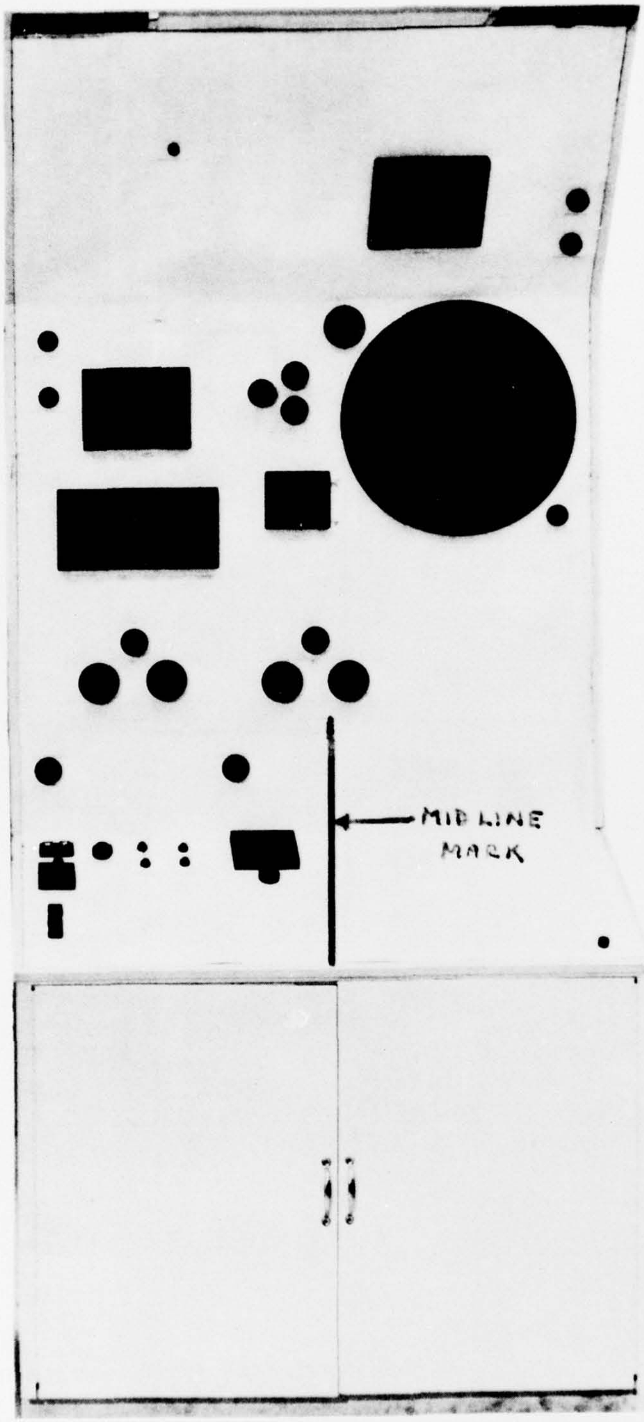

Fig. 15. Example of poor task-loading decision.

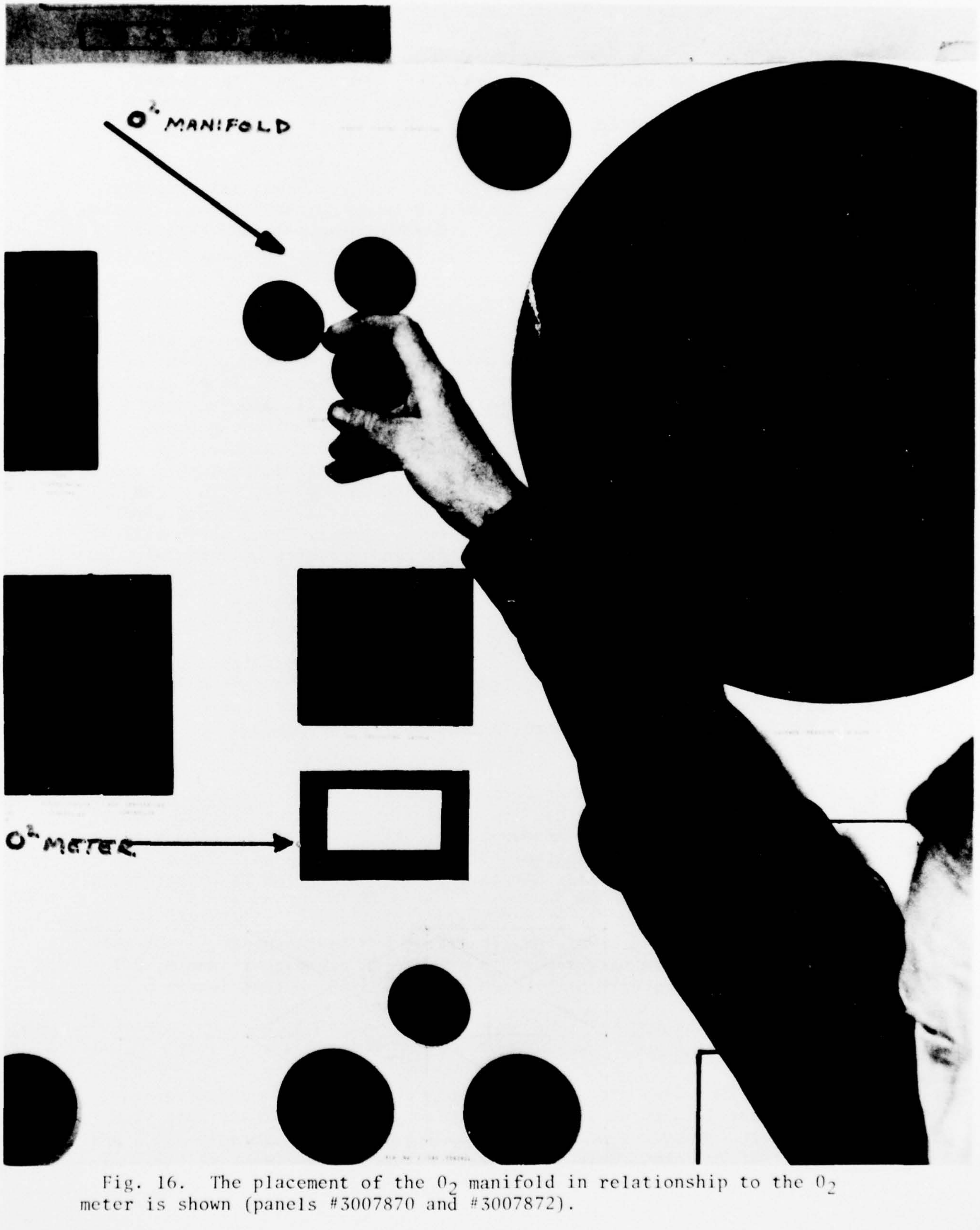

Fig. 16. The placement of the O_2 manifold in relationship to the O_2 meter is shown (panels #3007870 and #3007872).

to come in physical contact with valves they did not plan to operate while they were attempting to move any given component on the oxygen manifold. This observation would appear to validate a portion of the diver reports.

It should also be pointed out that the corresponding relationship between the oxygen manifold and the oxygen-level controller meter (bottom arrow on Fig. 16) is not optimized. A further discussion of this is found under the section of this paper labeled "Control-Display Relationships."

Functional Grouping

Chapanis and Lindenbaum (1959, pp. 1-7) have amply demonstrated that for optimal use, displays and controls should be arranged in logical patterns that have high control-function correspondence. Other sources (Human Factors for Designers of Naval Equipment, 1971) also recommend that control-related subsystems with similar functions should be grouped within the same general area on a control panel. For example, the environmental subsystems related to temperature control, humidity, and blower speed should be bounded as illustrated in Fig. 17. The three components which make up the environmental subsystem are grouped together and each component is further isolated by a boundary line, which visually separates it from other components. This configuration will minimize an operator'a visual searching, reduce the amount of physical motion required for operation, and enhance the speed of operator response with (theoretically) less chance for error.

In comparison, however, Fig. 18 indicates three similar components of the MRCC panel, which are labeled A, B, and C. Component A is the humidity control/indicator; B is the temperature control/indicator, and C is the blower fan/speed control/indicator for the atmospheric-conditioning system (ACS).

Although these components form part of the internal weather system of the hyperbaric chamber, they are physically separated by over 2 feet. Components A and B give the appearance of being part of the BIB pressure and mixed-gas indicators (to the left of the arrows labeled B and A), but their function is totally unrelated. This situation is unsatisfactory for the reasons given above.

While other examples of this condition can be shown, it is not the intent of this preliminary report to provide an exhaustive sample, but to indicate the existence of problems in this area so that future planning will be aided.

Operator Position

Saturation dives are usually of long duration with watchstanders on duty at least 4 hours at a time. Therefore, it is important that they be provided with console seats to minimize leg fatigue. Figure 19 shows one seating configuration, which falls within acceptable limits of Military

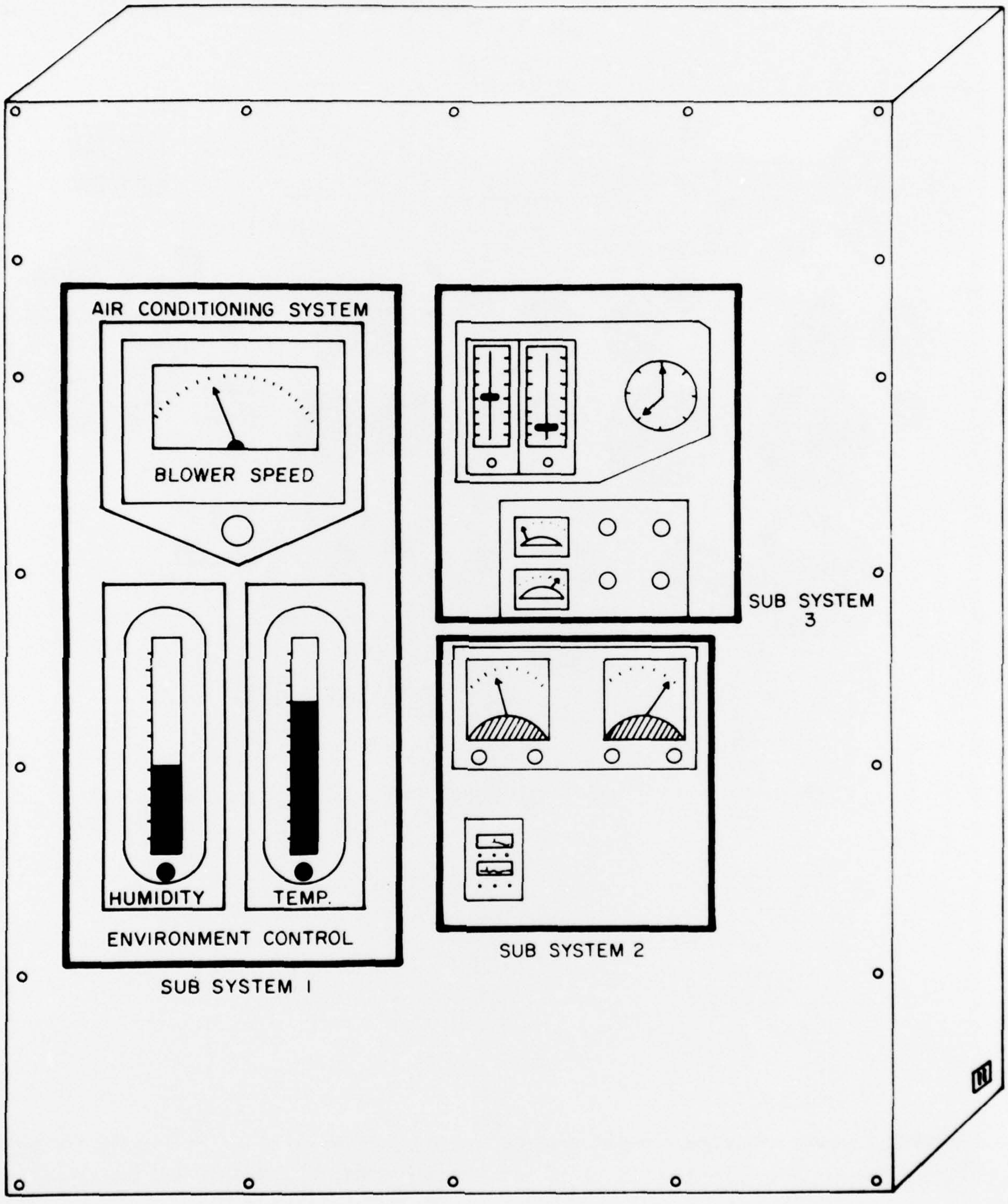

Fig. 17. An example of optimal control-function grouping, which assists an operator in locating information quickly without confusion.

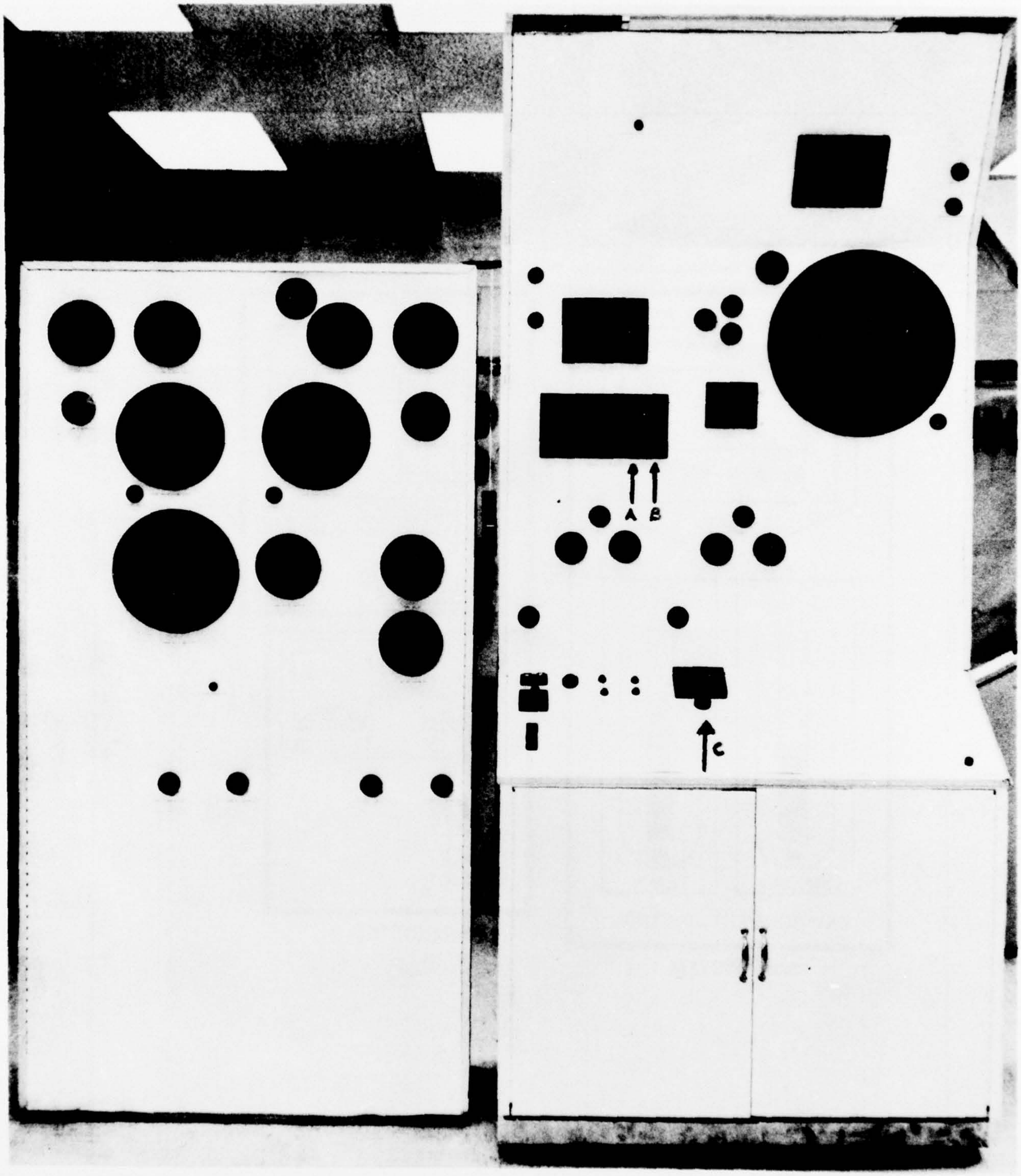

Fig. 18. MRCC panel #337870: The components of the environmental control system labeled A, B, and C are displayed. Note that they are not grouped together, but are separated by 23 inches. In addition, controls A and B appear to comprise part of the BIB gas meter controls.

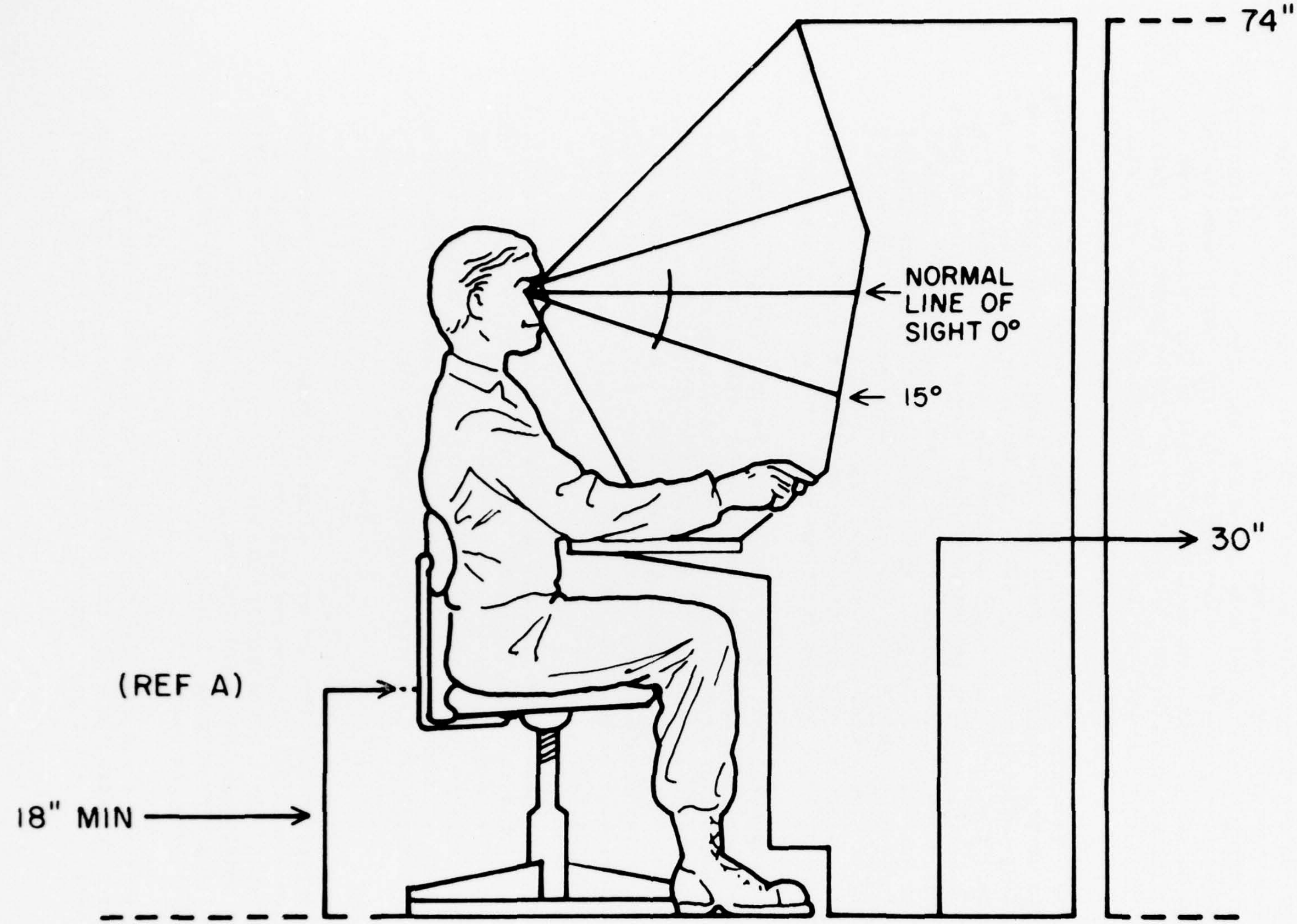

Fig. 19. A Human Engineering Standard for Seating Arrangement is shown. (Drawing based on information and drawings in Human Factors for Designers of Naval Equipment, Vols. I and II, 1971.)

Specifications (MIL-STD-1472A, 1970), and which was acceptable to Navy divers in the 5th through 95th percentile-height (Beatty and Berghage, 1972). When this seating arrangement was used as a criterion model, none of the existing control panel mock-ups under evaluation was satisfactory. For example, it was empirically determined that the 75th percentile Navy diver had access to less than an average of 64% of the controls from a seated position when Reference A (see Fig. 13) was extended to a full 22 inches. Even when the mock-ups were examined with the diver in a standing position, they were poorly instrumented from the standpoint of accessibility.

Table 1 displays the percentage of controls reached by both standing and seated control operators. Note that the range of accessibility from the standing position was 70% to 80%. The seated operator has much more difficulty: the percentage range averaged from 48% to 74% for the 5th, 25th, 50th, 75th, and 95th percentile-height operators. Figure 20 shows a seated diver at one control panel. He is representative of the 65th percentile Navy diver in height. When asked to reach for each control without stretching, only 50% of the controls were in his reach or in a good field of view. Even when the seat was raised from 18 inches to 29 inches (see Fig. 21) and the diver was asked to stretch his reach as far as possible, 6 control functions were still out of his reach.

It is suggested that the control panels be modified to accommodate the seated operator. As a minimum requirement, the controls should be repositioned so that Navy divers in the 25th to 75th percentile-height range have unobstructed access to at least 80% of all control functions from the seated position. One solution would be to mount controls on a hortizontal wrap-around console. In this manner the access area of the panel control surface would be increased by a greater factor compared to present designs (see Fig. 22).

Another problem stems from the configuration of the present control consoles, which do not accomodate the legs of the seated operator. (The seated operator is unable to get close to the instruments because there is no place for his legs/knees to fit into or under the console desk top.) A more accommodating design would allow the operator room for his legs to fit under the table top, as displayed in Fig. 13.

DISCUSSION

This brief description of our preliminary human factors engineering evaluation should make it obvious that the current control designs do not conform to basic human factors design criteria, which in turn will place an unnecessary burden on the operator. This situation can be reversed if proper systems planning is completed before final retrofit design decisions are made.

In general, there are five major areas to consider before any equipment is constructed: (1) the users' preferences, their anthropometic requirements, and their past learning experiences, particularly formal

TABLE 1

Percentage of controls reached by seated or standing operators using control panels #3007870, #3007871, and #3007872

Percentile Height	Panel # 3007870 n=50	Panel # 3007871 n=32	Panel # 3007872 n=35	Mean X
		Standing Position		
5	.54	.81	.71	.58
25	.60	.81	.71	.70
50	.64	.81	.80	.75
75	.88	.93	.80	.87
95	.88	.93	.94	.91
MEAN	.70	.85	.79	
		Seated Position		
5	.44	.68	.42	.51
25	.44	.68	.51	.54
50	.50	.78	.60	.62
75	.50	.78	.65	.64
95	.54	.81	.71	.68
MEAN	.48	.74	.57	

* n= number of components in each panel

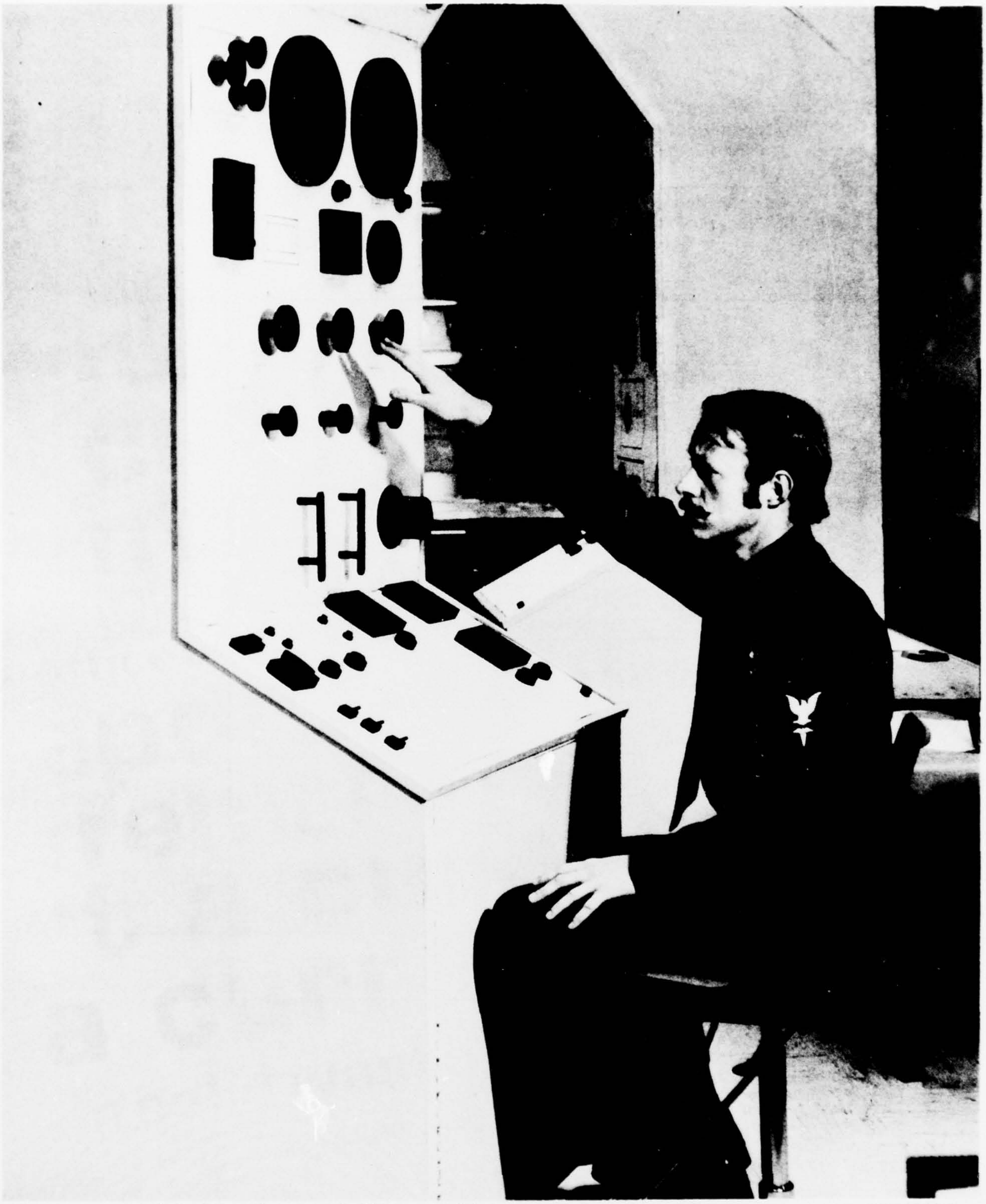

Fig. 20. A seated diver unable to reach selected control panel #3007875 is shown.

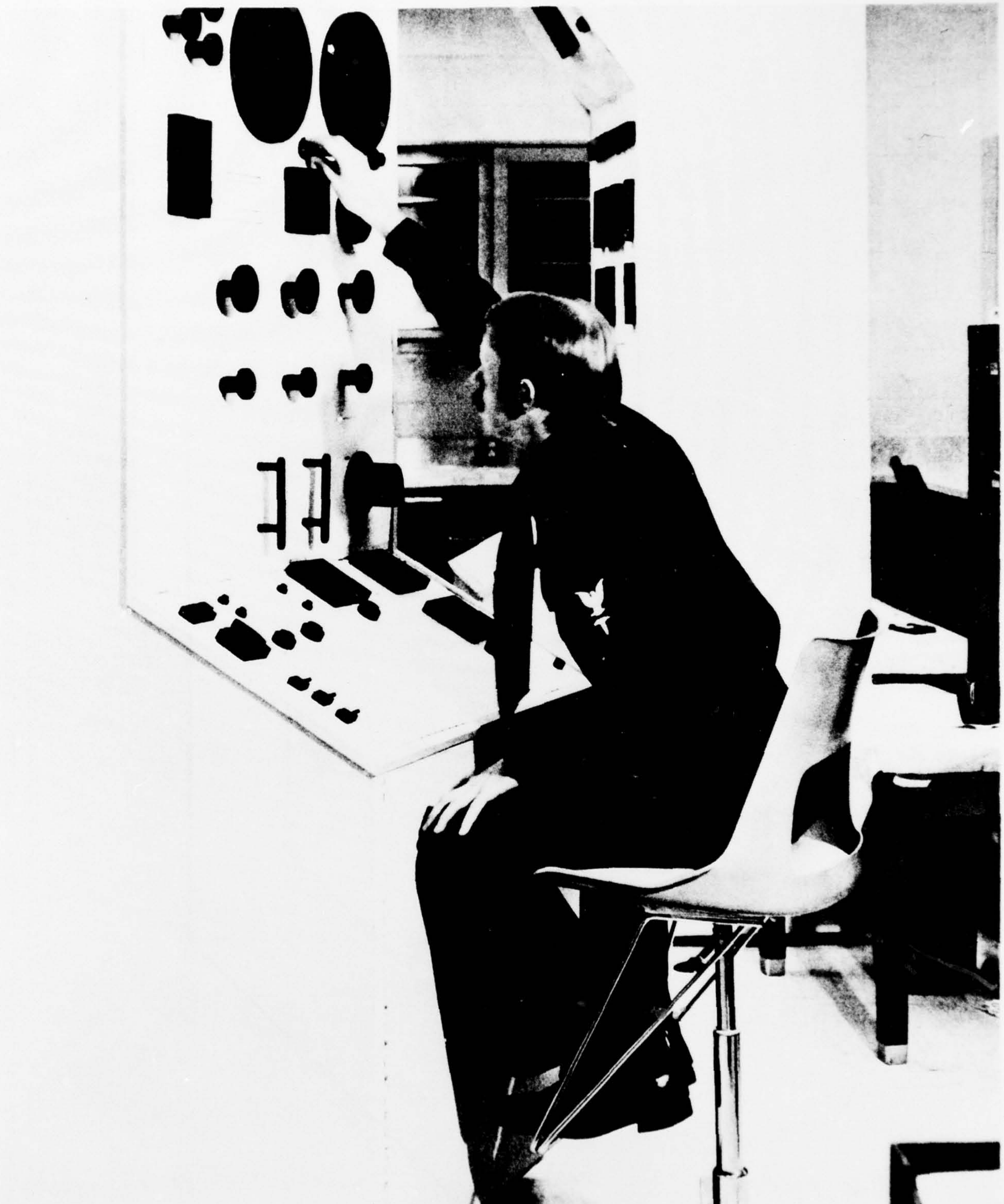

Fig. 21. A seated diver able to reach selected control panel #3007875 because his seat has been raised 11 inches.

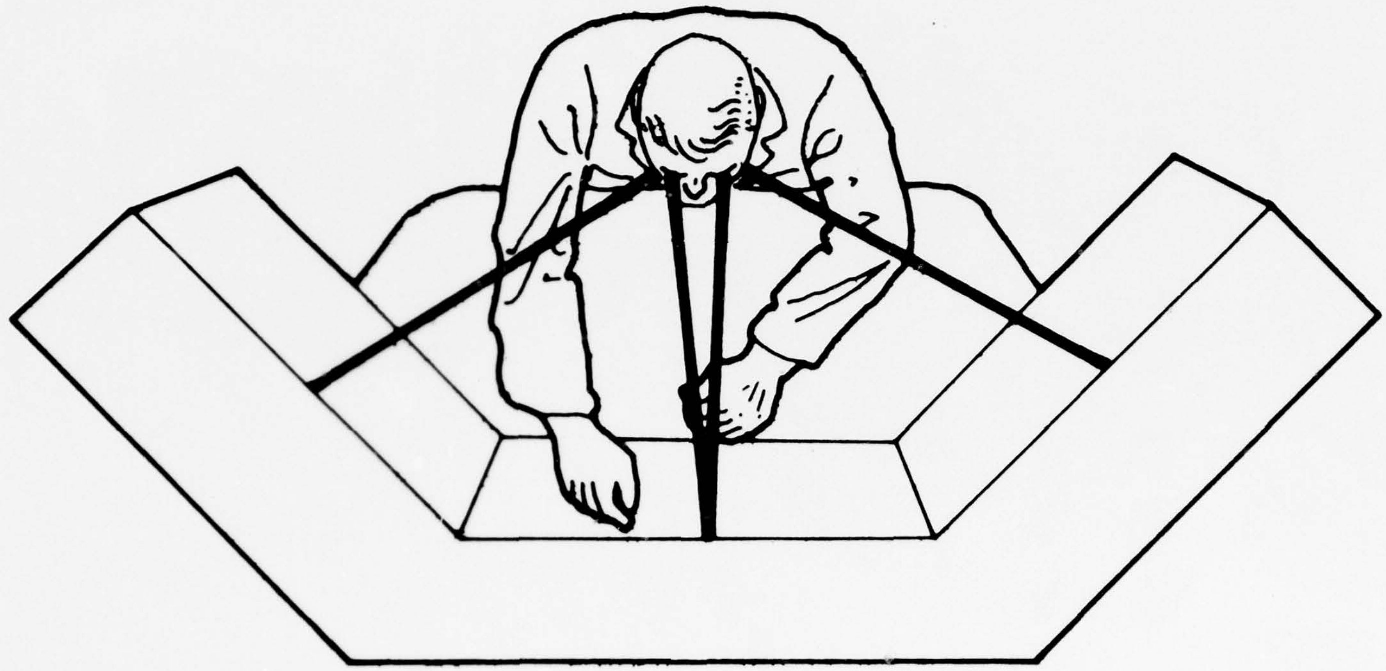

Fig. 22. Example of a horizontal wrap-around console. (Drawing based on information and drawings in Human Factors for Designers of Naval Equipment, Vols. I and II, 1971.)

training; (2) the mission for which the system was designed; (3) the environment in which both the man and equipment must effectively operate; (4) the types of tasks the equipment will require from the operator; (5) the frequency with which the tasks are performed and their order of priority. Finally, examine the interactive effect of these variables (operator, task, environment, equipment, mission) and determine the designs that maximize parameters most critical to mission success.

If attention is not focused on these issues, it is likely that the control system will offer less than its intended efficiency and purpose. That purpose is to provide smooth, reliable, and safe operation of the equipment and to insure the success of the mission. The control panel on the left of Fig. 23 is one of many alternate designs that are currently being compared with the contractor-supplied panel design (right side of Fig. 23). Notice the degree of body and hand movement required of the seated operator on the right for activation of the oxygen manifold. The operator on the left, however, has no difficulty in reaching 96% of the manual controls on his panel. Comparisons such as these will lead eventually to increased efficiency in operation and to over-all safety.

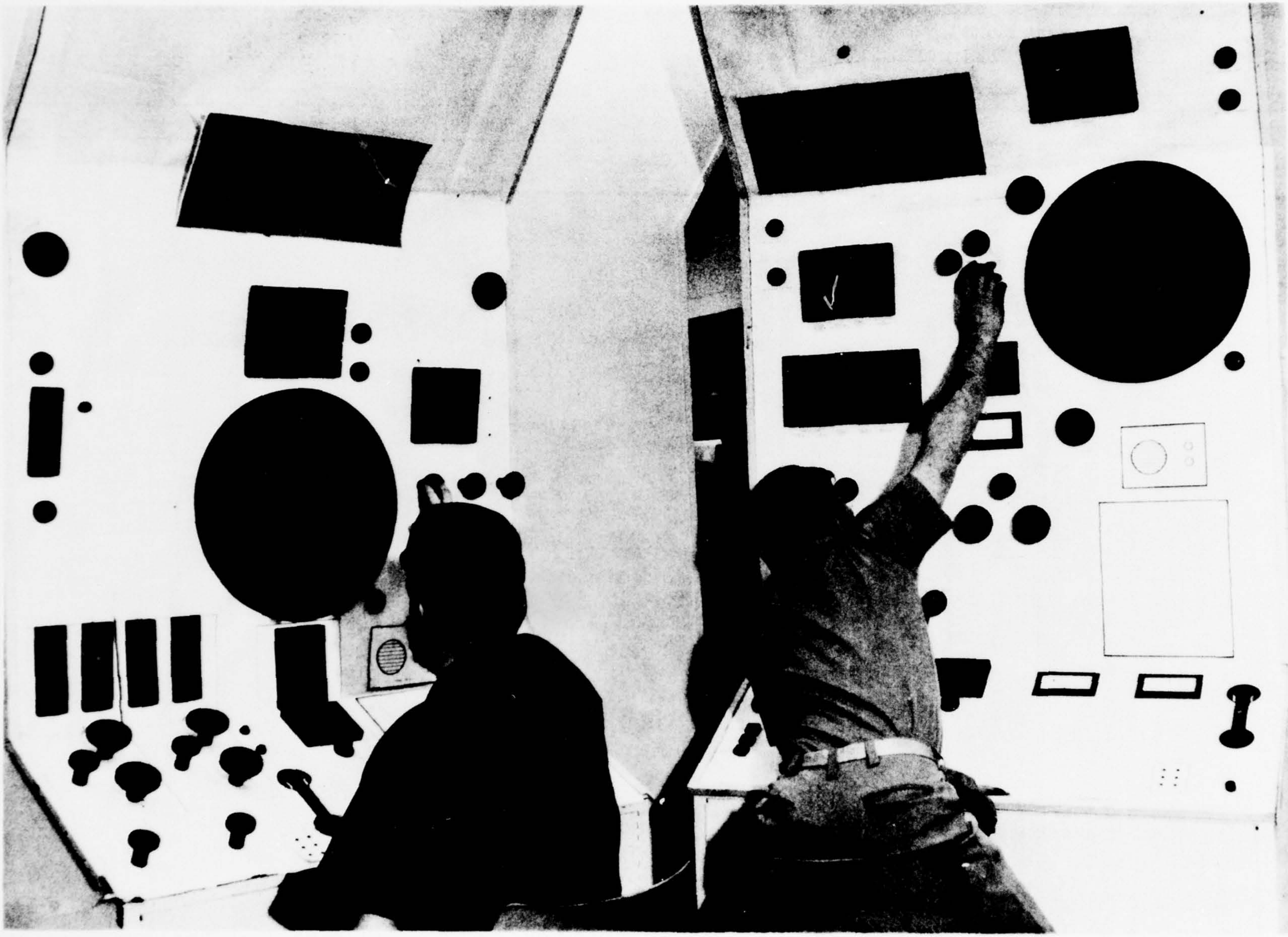

Fig. 23. The right console mock-up was constructed from contractors' plans; the left is a modification based on preliminary human factors studies.

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